LAKE ENHANCEMENT FEASIBILITY STUDY
WEST BOGGS LAKE

PREPARED FOR:
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EXECUTIVE SUMMARY

West Boggs Lake is a reservoir which was impounded in 1971 and located approximately 3 miles north of Loogootee, Indiana. The lake was originally impounded to have a surface area of 622 acres. The 7,870 acres of land that drain into the lake combined with the lake surface area yield a watershed area equal to 8,492 acres. The watershed is predominantly agricultural with the majority of the drainage entering into the lake through seven tributaries.

West Boggs Lake is currently experiencing cultural eutrophication (the impacts of human culture accelerating the decrease of the water quality) which has produced several concerns. Among these concerns are sedimentation, residential development along the shoreline, shoreline erosion, and watershed management practice problems, as well as declining lake water quality in general.

This study incorporated historical lake data and watershed land usage, field surveys and sampling programs, analysis of data, computer modeling of watershed inputs, analysis of restoration alternatives, and conclusions and recommendations to improve the longevity and quality of West Boggs Lake. A primary management regime was developed which consists of five responses which will address the management needs as well as address cost-effectiveness and recreational lake usage. The first primary response is to implement alternate watershed management practices. The second primary response is to address the human sewage disposal practices from residences throughout the watershed, particularly along the shoreline. The third primary response is to address the shoreline erosion presently occurring around the lake. The fourth primary response is to possibly construct sediment detention basins upstream of two key areas of the lake that have been impacted by excessive sedimentation. The fifth primary response is to develop and document a long term lake and watershed management plan which incorporates the first four responses. The logic and detail of each of these responses is provided within this report.

The Joint Daviess-Martin Park and Recreation Board is in an influential position to elicit the assistance of public officials and private citizens to cooperate in accomplishing the goals and recommendations presented in this study. Through planning and diligence, the Park Board can protect the quality of West Boggs Lake for years to come before exceeding reparation potential.

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Section 1. INTRODUCTION

1.1 West Boggs Reservoir and Watershed

West Boggs Reservoir is located approximately 3 miles north of Loogootee, Indiana, west of State Road 231. The reservoir and its watershed lie within Sections 1, 2, 3, 4, 5, 8, 9, 10, & 11, of Township 3 North, Range 5 West and Sections 21, 22, 23, 24, 25, 26, 27, 28, 33, 34, 35, 36, of Township 4 North, Range 5 West, on the U.S.G.S. Loogootee and Odon 7.5-Minute Quadrangle Maps both dated 1974.

West Boggs Lake is used for various recreational purposes such as swimming, boating and fishing by residents around the lake and the public. West Boggs Park lies adjacent to West Boggs Lake and provides additional recreational uses such as a public access boat ramp, boat rental, boat mooring sites, shoreline fishing area, handicapped fishing pier, beach, and campground (Fish Survey Report, 1987). West Boggs Lake is not used as a potable water supply.

The watershed is predominately agricultural with the majority of the drainage entering into the lake through seven tributaries from the agricultural sub-watersheds.

1.2 Physical Characteristics

The total watershed acreage for West Boggs Lake is 8,492 acres (1972, Fish Management Report). Several physical and morphometric characteristics of West Boggs Lake were calculated from contours shown on the above mentioned U.S.G.S. topographic maps and a bathymetric map prepared by the Division of Water of the Indiana Department of Natural Resources in 1974.

The lake was designed and originally impounded to have a surface area of 622 acres (1972, Fish Management Report). Approximately 50 acres or 8% of the lake's area lies in Martin County, the remaining 572 acres of 92% lies in Daviess County.

The design volume of the lake is 6,220 acre-feet (1972, Fish Management Report). According to the bathymetric map obtained from the IDNR Division of Water, there is a small area of the lake that has a depth of 30 feet; however, all fish management reports reference a maximum depth of 25 feet. The maximum depth located by Donan Engineering during the 1990 lake pool sampling survey was about 25 feet as well; consequently, a maximum depth of 25 feet will be used. The average depth (Volume/Area) is 12.5 feet.

The relative depth is the ratio of the maximum depth as a percentage of the lake at the surface, expressed as a percent. Most lakes have a relative depth of less than 2 percent, whereas deep lakes with a small surface area usually have a relative depth of greater than 4 percent. West Boggs Lake has a relative depth of 0.496% indicating that the lake is somewhat shallow compared to the surface area.

The shoreline length was found to be approximately 113,338 linear feet or 21.47 miles at pool. The shoreline development index is the ratio of the length of the shoreline to the circumference of a circle of area equal to that of the lake. Very circular lakes approach the minimum shoreline development value of unity (or 1). The higher the ratio, the more the lake deviates from a perfect circle. West Boggs Lake has a very high shoreline development index of 6.14 reflecting the numerous narrow coves and legs of the lake.

1.3 Water Quality Problems

There are several concerns at West Boggs Lake including sedimentation, residential development along the shoreline, shoreline erosion, and watershed management problems, as well as declining lake water quality.

1.4 Feasibility Study Objectives

The objectives of this study were to assess the current characteristics of the lake and the surrounding watershed. This also includes the identification of historical and existing eutrophication problems, their sources and relative contributions, the development of restoration alternatives, and the recommendation of the alternative found to be the most practical and potentially successful. This study included historical lake data and watershed land usage, field surveys and sampling programs, analysis of data, restoration alternatives, conclusions and recommendations, and references.

Section 2. DATA COLLECTION

2.1 Historical Data

The West Boggs Creek Reservoir construction was completed in August of 1971. A few water quality studies have been conducted on West Boggs Lake. These studies include water quality sampling in 1976, 1978, and 1989 by Indiana Department of Environmental Management (IDEM) representatives and subcontractors for the purposes of calculating a eutrophication index. Eight fish Management Reports were conducted by the Indiana Department of Natural Resources - Division of Fish and Wildlife between 1972 and 1989.

The reservoir was built with federal funds appropriated for P.L. 566 projects (Small Watershed Program projects) and is a multi-purpose structure. An eradication of all ponds within the 8,492 acre watershed containing undesirable fish (carp, gizzard shad, bullhead) was completed in August of 1971. Shurn Creek and Little Boggs Creek from the dam to the head waters were also treated. After the eradication, the reservoir and all eradicated ponds were stocked by the Division of Fish and Wildlife with desirable fish such as largemouth bass, channel catfish, bluegill, redear sunfish, and black crappie.

The fishery reports of 1972, 1973 and 1977 stated that West Boggs had become one of the most popular fishing waters in southern Indiana due to its expanding population with above average growth rates and excellent recruitment for all game species. The 1980 Fish Management Report stated that even though the West Boggs sport fishery was in good condition, gizzard shad had invaded the lake which may have a detrimental effect in the future by competing with sport fish.

The 1983, 1985 and 1987 Fish Management Reports state that there was an imbalance in the predator-prey relationship at West Boggs with the gizzard shad population growing and other undesirable species such as carp and yellow bass also present. The 1987 report suggested that one solution to the imbalance was a total eradication and restocking. It was suggested that the opinions of local anglers be considered before a decision be made. The 1989 report consisted of a creel survey conducted from April 1 to October 31, 1989. Despite some problems, anglers at West Boggs were generally pleased with the fishery, although the average size of panfish harvested was fairly small. It was finally suggested that a complete eradication project was not warranted at that time, but that it may become necessary in the future.

The historical data from the IDEM sampling events of 1976, 1978, and 1989 will be detailed in Section 3.0-10 entitled Eutrophication Index.

The Indiana Department of Natural Resources - Division of Nature Preserves was contacted to request information regarding the existence of rare and endangered species and high quality natural areas in the West Boggs Lake Watershed. The Indiana Natural Heritage Program's data bank was checked and a list containing two endangered species was provided. The first species is the bald eagle which has been observed during midwinter around West Boggs Lake. The second species is the loggerhead shrike which forages and nests in the general area from County Road 350 North to County Road 200 North, and from County Road 1000 East to County Road 1200 East. A description of the loggerhead shrike's physical characteristics, habitat, nesting, and range are included in the Appendix, along with a photograph.

2.2 Field Surveys

The initial field survey of West Boggs Lake was conducted on August 9, 1989, by Mr. Eric Welling, Project Manager and Environmental Scientist of Donan Engineering Co., Inc., Mr. Bill Jones, Director of the Environmental Systems Applications Center at the School of Public and Environmental Affairs (SPEA) at Indiana University, and Mr. Mark Pfister, graduate student at SPEA, to collect samples providing for the analysis of lake water quality, sediment composition, as well as plankton species and populations.

The lake water quality and plankton sampling was conducted at the lake's deepest point by the dam. Water samples were collected from the epilimnion (depth of 1 meter or about 3.3 feet) and the hypolimnion (depth of 6 meters or about 19.7 feet). The analytical values obtained from the epilimnetic and hypolimnetic samples were averaged for the purposes of the Eutrophication Index.

A detailed Quality Assurance/Quality Control (QA/QC) program is implemented at the SPEA for all lake sampling and laboratory analyses. This program incorporates the collection and analysis of several duplicates and field blanks as well as laboratory splits of samples during analysis. All standard deviations of the arithmetic means were within the 95% confidence limits of the laboratory standards for each laboratory method.

Sediment samples were taken at four different locations, on three of the major inlets, and at the lake pool station (Figure 1).

The equipment used during the lake sampling event consisted of a YSI 54A dissolved oxygen/temperature meter, YSI 33 conductivity meter, Corning 107 pH meter, Beckman EV3 Light transmission meter, Birge style 53 micron mesh closing plankton net, Wildco-Ekman dredge for sediment grab samples, Secchi disk, Kemmerer sampling bottle, and a Hummingbird depth finder on a 16-foot modified super Jon boat.

A visual aquatic vegetation survey and shoreline erosion survey of West Boggs Lake was conducted by Mr. Eric Welling and Ms. Karen Dearlove, former employee of Donan Engineering, on September 24, 1990. Plant species were identified and their frequency of distribution noted. Areas of shoreline erosion were documented as well.

Another survey was conducted by Mr. Edward Knust, Environmental/Soil Scientist at Donan Engineering, and Mr. Bob Smolik, Superintendent of West Boggs Park, on October 9, 1990, during a 1.0 inch storm event to collect the lake influent samples, flow data on the seven major inlets, and bacteria samples.

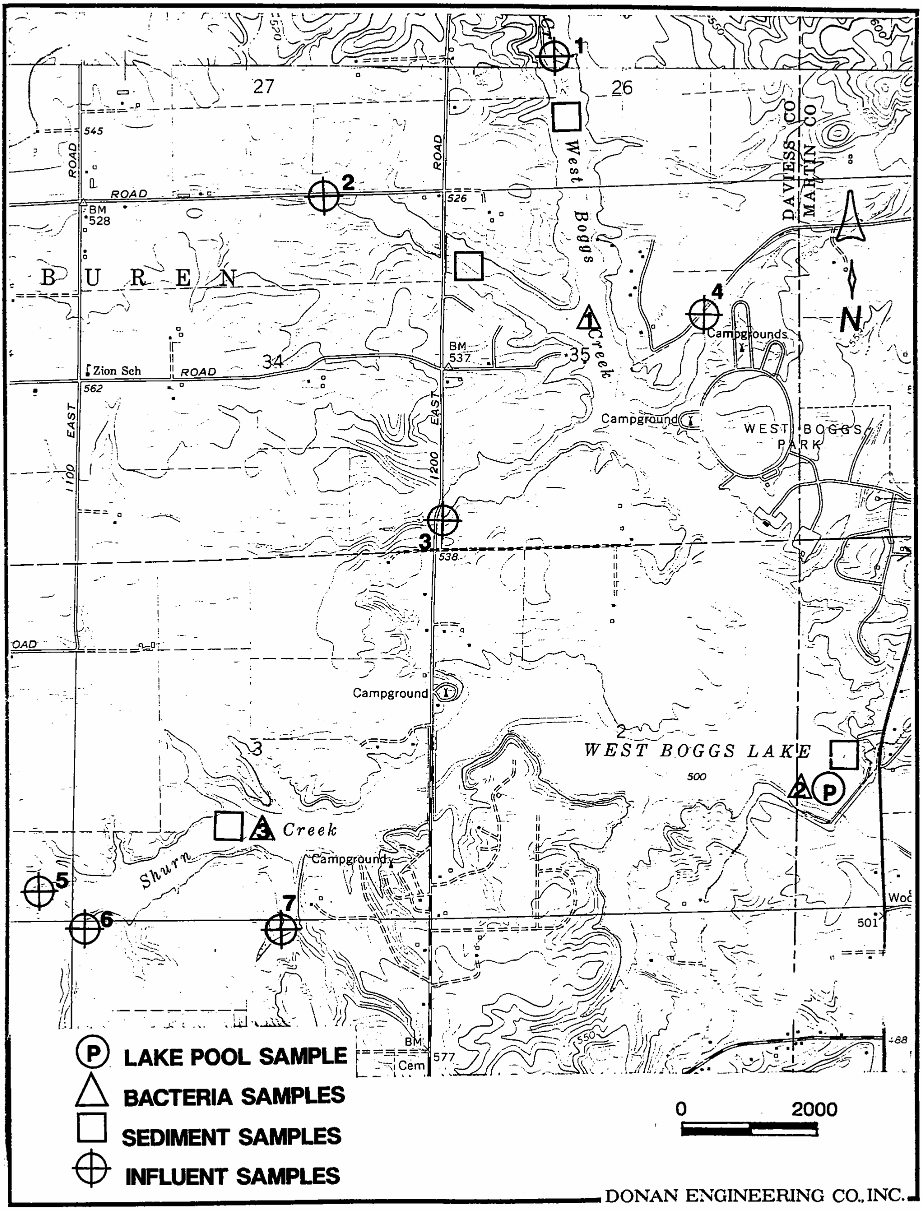


Figure 1. West Boggs Lake and Sample Stations

A final survey was conducted by Mr. Eric Welling and Mr. Edward Knust on October 15, 1990 to assess the extent of sedimentation that has occurred at West Boggs Lake. This was accomplished by using a sounding line from the side of a boat.

Mr. Bob Smolik, Mr. Bart Pitstick, Daviess County District Conservationist, and Mr. Ed Knust referenced historical and present aerial photographs, conducted interviews, and conducted visual field observations to complete the watershed land use verification. This was conducted during December of 1990 and January of 1991.

For the field and laboratory parameters, refer to Table 1.

TABLE 1

LAKE POOL

FIELD

Parameter	Equipment	Samples Collected
Temperature Profile	YSI 54A	1 meter intervals
Dissolved Oxygen Profile	YSI 54A	1 meter intervals
Conductivity Profile	YSI 33	1 meter intervals
pH Profile	Corning 107	1 meter intervals
Light Transmission	Beckman EV3	-percent of surface light at 3 feet -depth of 1 percent surface light
Plankton Tow	Birge style 53 micron mesh plankton net	-5 feet to surface -5 feet through the thermocline
Sediment Grab Sample	Ekman Dredge	1 composite sample
Secchi Disk reading		

LAB

Parameter		Analytical Method
Total Phosphorus		
	H_2SO_4-HNO_3 Digestion	424 CII
	Ascorbic Acid Method	424 F
Soluble Reactive Phosphorus		
	Ascorbic Acid Method	424 F
Organic Nitrogen		
	Semi-Micro-Kjeldahl Digestion	420 B
Nitrate		
	Nitrate Electrode Method	418 B
Ammonia		
	Ammonia-Selective Electrode Method	417E
Alkalinity		
	Titration Method	403
Plankton		
	-Preserved with Lugols solution in the field (1ml/100 ml sample) -Sedgwick-Rafter Cell Counts	

"Standard Methods for the Examination of Water and Wastewater"
AWWA-APHA-WPCF, 15th Ed.

3.0 Water Quality

The following data was obtained from the lake pool sampling event on August 9, 1990 and will be referenced throughout the remainder of this section:

Lake Name	Date Sampled	Z max(m)	Secchi(m)	(feet)
West Boggs	8/9/90	7	0.55	1.8

	Epi(mean)	Epi(SD)	Hypo(mean)	Hypo(SD)	Average Values
NO3(mg/l)	0.299	0.022	0.292	NA	0.30
NH3(mg/l)	0.025	NA	8.992	0.075	4.51
Org-N(mg/l)	2.236	0.027	ND	NA	1.12
SRP(mg/l)	0.004	0.001	0.303	0.007	0.15
Tot P(mg/l)	0.063	NA	0.509	0.018	0.29
Alk(mgCaCO$_3$/l)	74.288	0.026	120.225	NA	97.26
pH	8.5	---	7	---	7.75
Cond(umhos/cm)	210	---	245	---	227.50

Key
NA = not applicable
ND = not detectable
Z max(m) = maximum depth expressed in meters
Epi(mean) = Average value from the epilimnion
Epi(SD) = Standard Deviation of the mean from the epilimnion
Hypo(mean) = Average value from the hypolimnion
Hypo(SD) = Standard Deviation of the mean from the Hypolimnion
mg/l = milligrams per liter
NO3 = Nitrate
NH3 = Ammonia
Org-N = Organic Nitrogen
SRP = Soluble Reactive Phosphorus
Tot P = Total Phosphorus
pH = A measure of the acidity or alkalinity present
Cond = Conductance expressed in micromhos per centimeter
Alk = Alkalinity expressed as milligrams of calcium carbonate per liter

3.0-1 Temperature and Oxygen Profiles

A major indicator of the water quality in a lake is the temperature and dissolved oxygen profiles. These profiles can immediately provide information as to the general water quality of the lake.

In temperate and other regions, i.e. Indiana, many lakes of moderate depth (approximately 10 m or 32 ft) exhibit thermal stratification during the warmer months of the year. During this time, the surface waters are heated, largely by solar radiation, more rapidly than the heat is distributed by mixing. As the surface waters are warmed and become less dense, the relative thermal resistance to mixing gradually increases (Wetzel, 1983). Eventually the lake becomes stratified into three regions that are exceedingly resistant to mixing with each other. The epilimnion is an upper stratum of less dense, more or less uniformly warm, circulating water. The hypolimnion is the lower stratum of more dense, cooler, and relatively quiescent water lying below the epilimnion. In between these two strata is often a small transitory strata called the metalimnion.

Oxygen is the most fundamental parameter of lakes, aside from water itself. Dissolved oxygen is obviously essential to the metabolism of all aerobic aquatic organisms. Hence, the solubility and especially the dynamics of oxygen distribution in lakes are basic to the understanding of the distribution, behavior, and growth of aquatic organisms (Wetzel, 1983). Dissolved oxygen is a non-linear function of temperature. A lake can be undersaturated with respect to oxygen, saturated with oxygen, or super saturated with oxygen. There are different parameters and entities within a lake that control the percent saturation of dissolved oxygen.

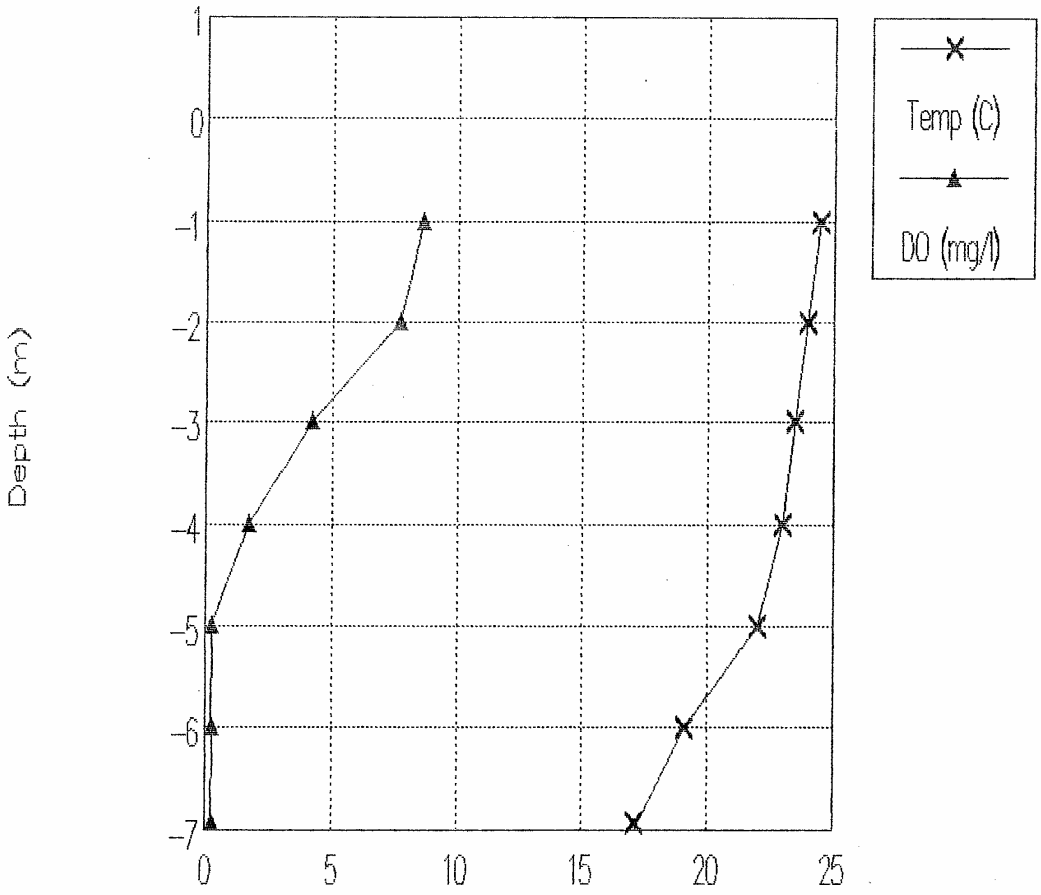
The temperature and dissolved oxygen in-situ profiles are displayed in Figure 2. The temperature data illustrate that the lake was only weakly thermally stratified at the time of sampling. The temperature readings ranged from 17.1 degrees Celsius (63^{o} F) at seven meters (22.96 feet) to 24.5 degrees Celsius (76.1^{o} F) at the water surface. The 17.1^{o} Celsius reading in the hypolimnion is unusually high. This often occurs when the temperature warming in the spring is gradual, allowing the lake to uniformly warm and completely mix for a longer period of time before stratifying. This slow warming scenario is supported by data presented by the National Oceanic and Atmospheric Association Climatological Data Reports, January through May.

Even though the stratification is weak, the resistance to mixing is great enough to not allow the epilimnion and hypolimnion waters to mix as is evidenced by the dissolved oxygen profile. As organic matter reaches the hypolimnion from the upper zones of the lake, the oxygen concentration of the hypolimnion becomes progressively more reduced and undersaturated from bacterial decomposition and plant and animal respiratory processes. The oxygen content of the hypolimnion of eutrophic (high in nutrients, with high organic production) lakes is depleted rapidly by oxidative processes.

FIGURE 2

West Boggs Lake

Temperature & Dissoved Oxygen



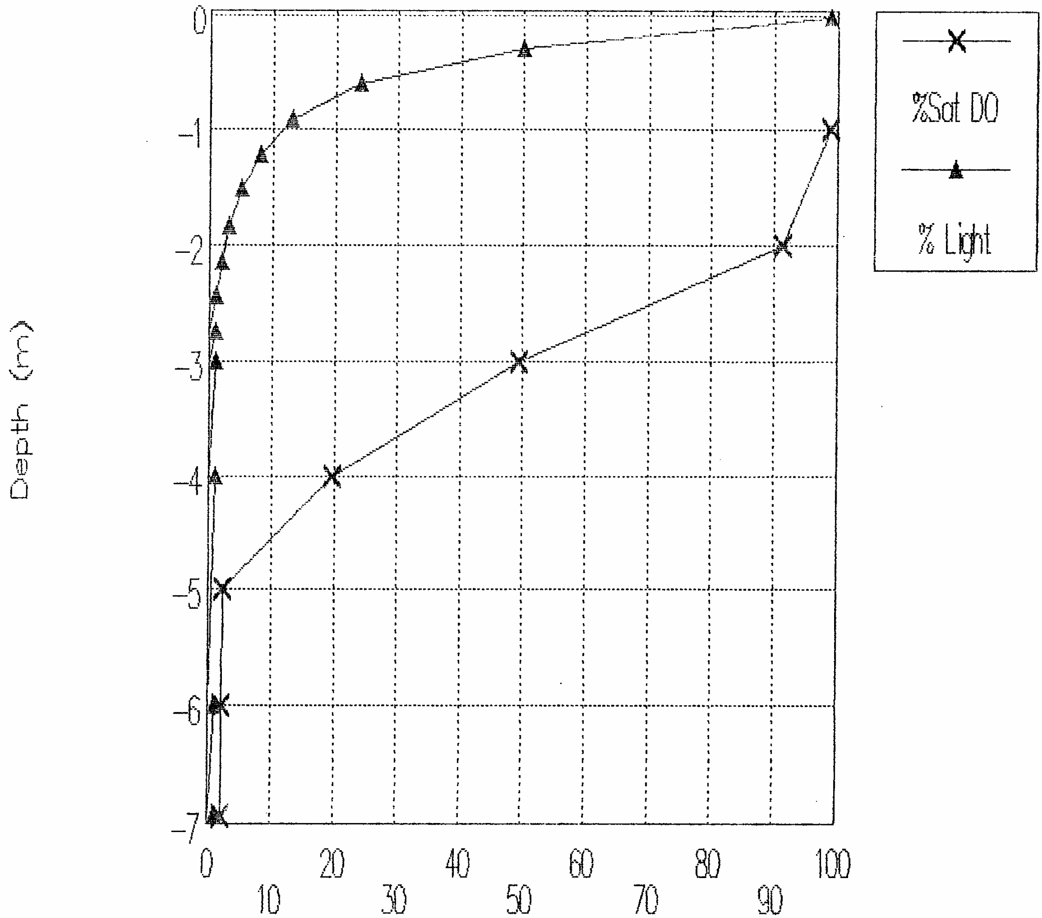
The resulting curve, in which the hypolimnion is anaerobic, is termed clinograde (Figure 2). There are two major features of this clinograde dissolved oxygen profile. The first is that the surface water is nearly 100 percent saturated with dissolved oxygen and the percent saturation moderately decreases until 5 meters (Figure 3). This indicates that there is not an abundance of phytoplankton, or algae, in the upper waters. Abundant phytoplankton often will supersaturate the upper waters with oxygen due to photosynthetic processes. This phenomenon was observed in 1973, 1983, and 1985 (Fish Management Reports, 1973, 1983, 1985). The second major feature is that the lower three meters are virtually anoxic having a reading of about 0.2 mg/l and a saturation level of around two percent. This indicates that the lower waters are not mixing with the oxygenated upper waters. This also indicates that there are oxygen consuming processes in the hypolimnion.

Fish will usually only occupy those waters that have sufficient oxygen to support their metabolic needs (usually greater than 4 or 5 ppm oxygen). During summer stratification those available waters become limited. According to the dissolved oxygen curve, there is limited oxygen for fish occupancy down to three meters or about ten feet. While fish have been known to move into waters of lower oxygen concentrations for short periods of time to take advantage of an available food source or more preferable temperature conditions, this level of oxygen is not optimal or preferable.

FIGURE 3

West Boggs Lake

% DO Saturation - % Light Transmission



Therefore, the oxygen levels were found to be optimal for fish habitat above 10 feet on the date of sampling. Previous Fish Management Reports demonstrate that the depth at which oxygen was optimal for fish has been relatively consistent. This level is very dependent upon the time of year that the reading is taken as well. Dissolved oxygen readings taken in the late summer will often exhibit a shallower depth for eutrophic, thermally stratified lakes. The following values are depth in feet to which there was optimal oxygen for fish (obtained from West Boggs Fish Management Reports):

	1972	1973	1977	1980	1983	1985	1987	(Yr.)
Oxygen Level	10	10	10	15	7	15	15	(Ft.)

3.0-2 Light Transmission

Solar radiation is of fundamental importance to the entire dynamics of freshwater ecosystems. Almost all energy that controls the metabolism of lakes is derived directly from the solar energy utilized in photosynthesis (Wetzel, 1983). Photosynthesis is limited by light availability. When the light availability falls below one percent (1%) of the surface light, photosynthesis is limited. The region above the one percent light level is known as the trophogenic zone. This zone is defined by light and no other parameters such as temperature and dissolved oxygen. Therefore, the trophogenic zone can be limited to the epilimnetic waters, or it can often extend well into the hypolimnetic waters. Below the one percent light level is known as the tropholytic zone. This zone is an aphotic deep stratum where decomposition of organic matter or respiration predominate. Donan Engineering recorded the light levels in one foot intervals until 8 feet (Figure 3). The one percent light level was found to be at eight feet (8 ft.) or about 2.5 meters. The trophogenic zone is exclusively in the epilimnion.

A vertical extinction coefficient can be calculated from a light transmission profile using the following equation (Wetzel, 1983):

$$nz = \ln I_o - \ln I_z$$

Where:
- n = extinction coefficient for that interval
- z = depth of the interval
- $\ln I_o$ = natural log of the light intensity at the lake surface
- $\ln I_z$ = natural log of the light intensity at the specified depth

This is one way to evaluate the transparency of a lake. The extinction coefficient values for natural lake waters vary from approximately 0.2 (about 80 percent transmission m^{-1}) per meter in very clear lakes to about 4.0 per meter in highly stained lake waters or lakes with very high biogenic turbidity (Wetzel, 1983). The average light extinction coefficient was calculated using the top eight feet light readings. The average was found to be approximately 2.14. This classifies the lake as having moderate transparency.

3.0-3 Secchi Disk Reading

A Secchi disk reading is another technique used to assess the transparency of water to light. An approximate evaluation of the transparency of water to light was devised about 1866 by an Italian scientist, Secchi, who observed the point at which a white disk lowered into the water was no longer visible (Wetzel, 1983). This method continues to be widely used owing to its simplicity. The Secchi disk transparency is the mean depth of the point where a weighted white disk, 20 cm in diameter, disappears when viewed from the shaded side of a vessel, and that point where it reappears upon raising it after it has been lowered beyond visibility. The Secchi disk transparency is essentially a function of the reflection of light from its surface, and is therefore influenced by the absorption characteristics both of the water and of its dissolved and particulate matter.

Previous West Boggs Fish Management Reports demonstrate that the Secchi Disk transparency (expressed in feet) is diminishing.

	1972	1973	1977	1980	1983	1985	1987	(Yr.)
Secchi Disk	8.5	4.5	5.08	3.0	2.0	2.25	2.0	(Ft.)

The Secchi Disk reading taken by Donan Engineering in 1990 was found to be 0.55 meters or 1.8 feet. According to the Indiana Lake Classification System and Management Plan (IDEM, 1986), 51 lakes (13%) sampled in Indiana had Secchi disk depths of 10 feet or more, 200 lakes (50%) had depths between 5 and 10 feet, 144 lakes (36%) had Secchi depths from 1 to less than 5 feet, and 5 lakes (1%) had Secchi depths of less than one foot. West Boggs Lake is currently very close to being in the lowest class or bottom one percentile of Secchi disk readings in the State. The low reading is more than likely due to the high suspended sediment content in the epilimnetic waters.

3.0-4 Conductivity

The specific conductance of lake water is the ability of a solution to conduct electrical current or electron flow. Conductance increases with increasing ion content and is expressed in micromhos per centimeter (umhos/cm - the reciprocal of ohms). The conductance readings for West Boggs are moderately low, 210 umhos/cm in the epilimnion and 245 umhos/cm in the hypolimnion. When the hypolimnion is anoxic, it is common for the conductivity reading to be higher due to the reducing environment which promotes the release of ions from the sediments.

3.0-5 pH Readings

A Bronsted-Lowry acid is defined as a species having a tendency to lose or donate a proton or hydrogen ion. A pH reading is a logarithmic measurement of the availability of hydrogen ions in a solution. Therefore, pH will specify the degree of acidity of an aqueous solution. The pH of natural waters ranges between the extremes of less than 2 to 12; however, the range of pH of a majority of open lakes is between

6 and 9 (Wetzel, 1983).

Previous West Boggs Fish Management Reports demonstrate that the pH readings at West Boggs have been consistent.

	1972	1973	1977	1980	1983	1985	1987	(Yr.)
pH-Epi	8.0	8.8	8.7	9.0	9.5	N/A	8.5	(pH Units)
pH-Hypo	6.8	7.0	7.5	7.5	7.0	N/A	7.3	(pH Units)

Two in-situ pH measurements were taken at West Boggs during our 1990 sampling. The pH of the epilimnetic waters was 8.5, the pH of the hypolimnetic waters was 7. These values are also consistent with previous data. These values are common in more productive or eutrophic lakes. The pH is strongly influenced by various biologically mediated reactions. Most obvious is the photosynthetic utilization of CO_2 in the trophogenic zone, which tends to reduce CO_2 content and to increase pH. In the tropholytic zone, the respiratory generation of CO_2 tends to decrease pH (Wetzel, 1983).

3.0-6 Alkalinity

Alkalinity of a water is its acid neutralizing capacity. It is the sum of all titratable bases whose equilibrium constants lie above the titration end point. In most fresh water systems, this will only include the carbonate system anions or CO_3^{--}, $H_2CO_3^{-}$, OH^{-}, and the negative value of H^{+}. This value is obtained by titrating a water sample with a known acid normality or concentration to a known pH endpoint of 4.5 for total alkalinity. Conveniently, the pH equivalence point of 4.5 also represents an approximate threshold beyond which most life processes in natural waters are seriously impaired. Thus alkalinity is a convenient measurement for estimating the maximum capacity of a natural water to neutralize acidic wastes without permitting extreme disturbance of biological activities in the water (Stumm & Morgan, 1981). Alkalinity concentrations usually range from 20 mg/l to 200 mg/l as $CaCO_3$ (Lind,1985).

Previous Fish Management Reports demonstrate that the alkalinity at West Boggs has varied somewhat, but ranged from poor to moderate buffering capacity.

	1972	1973	1977	1980	1983	1985	1987	(Yr.)
Alk-Epi	95.8	75.3	85.5	75.0	41.0	N/A	47.9	(mg/L as
Alk-Hypo	185	137	154	171	68.4	N/A	61.6	$CaCO_3$)

An alkalinity titration was conducted on a sample of the epilimnetic waters and a sample of the hypolimnetic waters. The epilimnion has an alkalinity value of 74.288 mg/l as $CaCO_3$; the hypolimnion has an alkalinity value of 120.225 mg/l as $CaCO_3$. This demonstrates that the alkalinity has dramatically risen from values recorded in 1983 and 1987 to values similar to those previously seen from 1972 to 1980.

3.0-7 Phosphorus

The control of nutrient loading to a lake is very important. Phosphorus is responsible for limiting primary production in most freshwater systems and is consequently the principal focus in nutrient studies. Phosphorus is used in nearly all phases of metabolism, particularly in the energy transformation of phosphorylation reactions during photosynthesis. Phosphorus is required in the synthesis of nucleotides, phospholipids, sugar phosphates, and other phosphorylated intermediate compounds. Further, phosphate is bonded, usually as an ester, in a number of low-molecular-weight enzymes and vitamins essential to algal metabolism (Wetzel, 1983).

Phosphorus exists in many various forms in lakes. Two analytical tests were conducted to evaluate the phosphorus concentrations at West Boggs. The first test determines the concentration of total phosphorus. This test begins with a sulfuric acid-nitric acid digestion that releases all forms of bound phosphorus into solution (Standard Methods, Method 424 CII,1989). The sample is then quantified using the ascorbic acid method (Standard Methods, Method 424 F, 1989). This value represents the total concentration of all phosphorus forms whether suspended or bound in organic materials. The second test determines the concentration of soluble reactive phosphorus. This procedure begins by filtering the water sample in the field through a 0.45 micron membrane filter. The filtrate is then taken back to the laboratory and quantified by using the ascorbic acid method (Standard Methods, Method 424 F, 1989). This value represents the amount of phosphorus present that is most often assimilated by aquatic biota. It primarily consists of orthophosphate even though a small fraction of any condensed phosphates are usually hydrolyzed as well.

The total phosphorus concentrations at West Boggs were found to be 0.063 mg/l in the epilimnion and 0.509 in the hypolimnion. If a lake is eutrophic (productive), total phosphorus concentrations of 0.03 to 0.100 mg/l can be expected. If a lake is hypereutrophic (extremely productive), total phosphorus concentrations greater than 0.100 mg/l can be expected (Wetzel, 1983). Therefore, the epilimnetic waters indicate that West Boggs is in the eutrophic category. The hypolimnion can be classified as exhibiting hypereutrophic conditions. This however, is common in eutrophic, thermally stratified lakes that have an anoxic hypolimnion. The phosphorus usually comes from two major sources in the hypolimnion. First, the decomposition of organic matter releases phosphorus into the hypolimnion. Second, under the reducing or anoxic conditions, the sediments can release phosphorus into the hypolimnion. Since the hypolimnion can not circulate with the epilimnetic waters, the concentration of phosphorus continues to increase over the summer.

The soluble reactive phosphorus concentrations at West Boggs were found to be 0.004 mg/l in the epilimnion and 0.303 mg/l in the hypolimnion. If a lake is productive or has numerous algae in the epilimnion, it is common to see very low soluble reactive phosphorus concentrations in the late summer due to the algal assimilation. The concentration in the hypolimnion is high due to the same reasons discussed for total phosphorus. It is worthy to note that the total phosphorus concentration also includes soluble reactive phosphorus.

Therefore, of the 0.509 mg/l of total phosphorus observed in the hypolimnion, 0.206 (0.509 - 0.303) was organically bound or non-soluble phosphorus.

3.0-8 Nitrogen

Nitrogen can also play a major role in aquatic biota metabolism and can expedite the eutrophication process within a lake. The phytoplankton productivity of infertile, oligotrophic lakes is often limited by the availability of phosphorus. As phosphorus loading to fresh waters increases and lakes become more productive, nitrogen often becomes the limiting nutrient for plant growth (Wetzel, 1983). Excessive loading of these nutrients permits increased plant growth until other nutrients and/or light availability become limiting (Wetzel, 1983). Nitrogen exists in either an organic or inorganic form. Organic nitrogen is bound to an organic molecule such as an amino acid, proteins, humic or other complex compounds. Inorganic nitrogen exists in three major forms, nitrate ions (NO_3^-), ammonium ions (NH_4^+), and molecular nitrogen (N_2). Several other intermediate forms of inorganic nitrogen exists, but are often quickly converted to one of the above stable nitrogen forms due to reduction-oxidation potentials. When nitrates are assimilated, they must be reduced to ammonium ions before they can be used by plants. Therefore, ammonium ions or ammonia is the most energy efficient source of nitrogen for plants and algae and is often selected over other forms of nitrogen to meet nitrogen requirements. Oxidized inorganic and organic forms of nitrogen in the hypolimnion often contribute to hypolimnetic oxygen depletion as well.

Three analytical tests were conducted to evaluate the nitrogen concentrations at West Boggs. The first test determines the concentration of ammonium ions or ammonia (NH_4^+ or NH_3). This was accomplished by the Ammonia Selective Electrode Method (Standard Methods, Method 417 E, 1989). The second test determines the concentration of nitrate (NO_3^-). This test was accomplished by using the Nitrate Electrode Method (Standard Methods, Method 418 B). The third test determines the concentration of organic-nitrogen (Org-N). This test was accomplished by using a Semi-Micro Kjeldahl Digestion (Standard Methods, Method 420 B), and an ion chromatograph.

The ammonia concentrations at West Boggs were found to be 0.025 mg/l in the epilimnion and 8.992 mg/l in the hypolimnion. If a lake is eutrophic or productive, low ammonia concentrations, i.e. 0.025 mg/l, can be expected in the epilimnion due to algal assimilation. The hypolimnion concentration of almost 9 mg/l is very high. However, when appreciable amounts of organic matter such as dead algae reach the hypolimnion, ammonia nitrogen will accumulate due to microbiologically mediated degradation processes. This accumulation greatly accelerates as the hypolimnion becomes anoxic and the reduction-oxidation (redox) potential is lowered. Large amounts of ammonium ions can be released from the sediments under these conditions as well.

The nitrate concentrations at West Boggs were found to be 0.299 mg/l in the epilimnion and 0.292 mg/l in the hypolimnion. These are relatively low values. Concentrations of nitrate range from undetectable levels to nearly 10 mg/l in unpolluted fresh waters, but are highly variable seasonally and spatially (Wetzel, 1983). As previously mentioned, nitrate concentrations are less significant than ammonia concentrations to phytoplankton and other aquatic vegetation.

The organic nitrogen concentrations at West Boggs were found to be 2.236 mg/l in the epilimnion and below the detection limit in the hypolimnion. The analytical procedure for identifying the organic nitrogen detected all nitrogen forms in the negative three oxidation state which includes most of the dissolved organic nitrogen (DON) and particulate organic nitrogen (PON). The presence of plankton species in the epilimnion is more than likely the explanation of the observed high organic nitrogen concentration. The low hypolimnion concentration reflects that there is primarily inorganic nitrogen present with little organic matter.

3.0-9 <u>Phytoplankton and Zooplankton</u>

The phytoplankton and zooplankton perform important functions in the overall stability and quality of an aquatic ecosystem. The word "plankton" means limited powers of locomotion and subject to distribution by water movements. Phytoplankton, also known as algae or plants, are the producers in the aquatic food chain. The zooplankton are small animals that feed on the phytoplankton and thus occupy the trophic level of primary consumers. Planktivorous fish (fish that eat plankton) in turn feed on the zooplankton as secondary consumers and piscivorous fish (fish that eat animals) feed on the planktivorous fish as tertiary consumers.

Excessive algal growth is likely to occur when an abundance of nutrients are entering a lake. This increased algal growth can have several negative effects on a lake. Excessive algae will decrease the transparency of the epilimnetic waters. As the algae die, they drift from the trophogenic zone to the hypolimnetic waters where they are microbiologically decomposed. These decomposition reactions are the primary consumptive process of oxygen from the hypolimnetic waters (Wetzel, 1983). The resultant impact on the biology of the lake is dramatic, particularly, the fishery of the lake.

The plankton were sampled at West Boggs by using a closing plankton net. Two tows were conducted, one from five feet to the surface, the other was through the thermocline from 19 feet to 14 feet. The results of the tows are displayed in Tables 2 & 3. <u>Aphanizomenon</u>, a blue-green algae (Cyanophyta) and <u>Synedra</u>, a diatom (Chrysophyta), are commonly found in eutrophic and hypereutrophic lakes and characteristically can cause taste and odor problems in lakes. The <u>Chaoborus</u> or phantom midge larvae is the larval stage of an adult "Culicidae" or mosquito. <u>Polyarthra</u> is a type of Rotifer (Rotifera). Rotifers are zooplankton (microscopic animals) that feed on algae, bacteria, and detritus (all non-living organic matter, both dissolved and particulate). They have

TABLE 2

PLANKTON SPECIES COMPOSITION IN WEST BOGGS LAKE

(FIVE FEET TO SURFACE TOW)

SPECIES	ABUNDANCE (#/l)
Blue-Green Algae (Cyanophyta)	
Aphanizomenon	832
Chroococcus	42
Rhabdoderma	5946
Diatoms (Chrysophyta)	
Synedra	83
Rotifers (Rotifera)	
Polyarthra	166
Pompholyx	374
Arthropods (Arthropoda)	
Nauplii (Order: Copepoda)	166
TOTAL COUNT	7609 cells/liter
EUTROPHY POINTS	1
BLUE-GREEN DOMINANCE	5
TOTAL EUTROPHY POINTS FOR SURFACE TOW	**6**

TABLE 3

PLANKTON SPECIES COMPOSITION IN WEST BOGGS LAKE

(FIVE FOOT THERMOCLINE TOW)

SPECIES	ABUNDANCE (#/l)
<u>Blue-Green Algae (Cyanophyta)</u>	
Rhabdoderma	74
<u>Rotifers (Rotifera)</u>	
Pompholyx	74
<u>Arthropods (Arthropoda)</u>	
Chaoborus (Order: Diptera)	0.25
TOTAL COUNT	148.25 cells/liter
EUTROPHY POINTS	0
BLUE-GREEN DOMINANCE	no
TOTAL EUTROPHY POINTS FOR THERMOCLINE TOW	**0**

cilia (small hair-like extensions from a cell) that move to assist in both locomotion and in movement of food particles towards the mouth. The order of Copepods are another type of zooplankton. Larval stages of copepods are called Nauplii. The remaining planktonic species identified from West Boggs are not very common in most lakes. Very little is known about the ecology or dynamics of Rhabdoderma, Pompholyx, and Chroococcus.

3.0-10 Eutrophication Index

Eutrophication is defined as "The process of excessive addition of inorganic nutrients, organic matter, and/or silt to lakes and reservoirs, leading to increased biological production and a decrease in volume" (Cooke, 1986). Eutrophication has also been described as a multifaceted term generally associated with increased productivity, structural simplification of biotic components and reduced stability (Wetzel, 1983).

Eutrophication is a natural process that occurs with all lakes. It is useful to view a lake's trophic progress by simplifying it to these three phases:*

- Newly formed lakes or reservoirs undergo an initial oligotrophic or unproductive phase during which the nutrient concentrations and phytoplankton biomass increase slowly over time. For some natural lakes, this can last hundreds or thousands of years.

- Inputs of nutrients from the watershed and recycling of nutrients from the sediments eventually will equal the export of nutrients through the lake's outlet and or by permanent loss to the sediments. This phase promotes a trophic equilibrium which is characterized by relatively stable and unchanging nutrient concentrations and biological production. This phase is often the most desirable for good fisheries.

- The trophic equilibrium phase comes to an end when sedimentation reduces the lake volume and mean depth beyond a certain point. After this point is achieved, the littoral (shallow waters near the shoreline) plant community rapidly expand over the entire lake, and completely dominate the metabolism of the lake.

* (adopted from IDEM Indiana Classification System and Management Plan, 1986)

A eutrophication index is a systematic way to rank a group of lakes for comparative purposes. There have been various eutrophication indices developed. The index that is used by the Indiana Department of Natural Resources for the purposes of evaluating lakes under the "T by 2000" Lake Enhancement Program is an index that was developed by Harold BonHomme with advice and consultation of other Indiana State Board of Health personnel. This index assigns points for lake trophic parameters to give scores ranging from 0 (highest quality) to 75 (lowest quality). The index utilizes the trophic parameter information gathered during the field surveys.

The index results can be categorized into four classes of lakes. Class One lakes exhibit the highest quality and have an index range from 0 to 25. Class Two lakes exhibit intermediate quality, are slowly moving toward senescence, are impacted by the activities of man, and have an index range from 26 to 50. Class Three lakes exhibit lowest quality, support extensive concentrations of aquatic weeds and algae during the summer, have impaired lake uses, and have an index range from 51 to 75. Class Four lakes are bodies of water in an advanced state of senescence that exhibit shallowness, low nutrient profiles due to macrophyte uptake, low plankton counts due to macrophyte dominance, and an index range similar to Class One lakes.

West Boggs Lake was evaluated for water quality in 1976, 1978, and 1989 by the Indiana Department of Environmental Management (IDEM). The following is a summary of the data which was available from the IDEM (Pers. Comm John Winters, IDEM, 1991):

May 27, 1976 - Average Water Column Data

Parameter	Average Value
Ammonia	1.81 ppm
Nitrate & Nitrite	5.56 ppm
Organic Nitrogen	1.44 ppm
Soluble Reactive Phosphorus	0.15 ppm
Total Phosphorus	0.18 ppm
pH	7.8
Secchi Disk Depth	2.1 ft.
1% Light Level	8.0 ft.

(No other data was available from the IDEM records, - including plankton data sheets)

Total EI value = 45 - Class Two Lake

June 23, 1978

Parameter	Surface Waters	Bottom Waters
Ammonia	0.1 ppm	1.1 ppm
Nitrate & Nitrite	0.1 ppm	< 0.1 ppm
Total Kjeldahl Nitrogen	1.3 ppm	1.8 ppm
Total Phosphorus	0.08 ppm	0.19 ppm

(No other data was available from the IDEM records, - including plankton data sheets)

Total EI value = Not Calculated

June 29, 1989

Parameter	Surface Waters	Bottom Waters
Ammonia	0.110 ppm	3.503 ppm
Nitrate & Nitrite	5.525 ppm	5.588 ppm
Organic Nitrogen	1.792 ppm	1.078 ppm
Total Phosphorus	0.103 ppm	0.249 ppm
Soluble Reactive Phosphorus	0.006 ppm	0.300 ppm
Alkalinity	73.16 mg/l	106.596 mg/l
pH	8.7	6.8
Conductivity	220 umhos	250 umhos
Percent light at 3 ft.	19%	
1% Light Level	8 ft.	
Percent Oxygen Sat. at 5 ft.	72.8%	
Percent of Water Column with Oxygen > 0.1 ppm	25%	
Secchi Disk Depth	2.1 ft.	

(No other data was available from the IDEM records, - including plankton data sheets)

Total EI value = 41 - Class Two Lake

A Eutrophication Index of 33 was calculated for West Boggs Lake using 1990 data collected by Donan Engineering and is displayed in Table 4. This also classifies West Boggs Lake as a Class Two lake although the actual value is lower than the previous two calculations.

There were some differences between the four data sets (1976, 1978, 1989, & 1990) with respect to nitrate, ammonia, and oxygen concentrations, however, the majority of the historical data parameters are very similar to our 1990 data. Discrepancies between chemical and physical parameters is not uncommon. A trophic parameter may show considerable variation both seasonally and spatially (sampling points throughout the lake); therefore, a single sampling event is only a "snapshot" in time of continually changing processes and will vary.

According to the Indiana Classification System and Management Plan (IDEM, 1986), 44 reservoirs were classified as Class One lakes for a total of 31,157 acres, 62 reservoirs were classified as Class Two lakes for a total of 14,748 acres, and 44 reservoirs were classified as Class Three lakes for a total of 2,813 acres. Therefore 64% by area of the reservoirs are classified as Class One, 30% by area are Class Two, and 6% by area are Class Three.

3.1 Sediment Nutrient Analysis

Sediment samples were taken at four different locations; three at major inlets, and one at the lake pool station (Figure 1) using an Eckman sediment dredge. The samples were forwarded to EMS Laboratories in Indianapolis, Indiana, for

TABLE 4. ISBH LAKE EUTROPHICATION INDEX
WEST BOGGS LAKE - AUGUST 9, 1990

Parameter and Range	Range Observed	Eutrophy Points
I. Total Phosphorus (ppm)		
A. At least 0.03		1
B. 0.04 to 0.05		2
C. 0.06 to 0.19		3
D. 0.2 to 0.99	0.29	>4<
E. 1.0 or more		5
II. Soluble Phosphorus (ppm)		
A. At least 0.03		1
B. 0.04 to 0.05		2
C. 0.06 to 0.19	0.15	>3<
D. 0.2 to 0.99		4
E. 1.0 or more		5
III. Organic Nitrogen (ppm)		
A. At least 0.5		1
B. 0.6 to 0.8		2
C. 0.9 to 1.9	1.12	>3<
D. 2.0 or more		4
IV. Nitrate (ppm)		
A. At least 0.3	0.295	>1<
B. 0.4 to 0.8		2
C. 0.9 to 1.9		3
D. 2.0 or more		4
V. Ammonia (ppm)		
A. At least 0.3		1
B. 0.4 to 0.5		2
C. 0.6 to 0.9		3
D. 1.0 or more	4.51	>4<
VI. Dissolved Oxygen (Percent Saturation at 5 ft. from surface)		
A. 114% or less	96.82%	>0<
B. 115% to 119%		1
C. 120% to 129%		2
D. 130% to 149%		3
E. 150% or more		4

TABLE 4. ISBH LAKE EUTROPHICATION INDEX (CON'T.)
WEST BOGGS LAKE - AUGUST 9, 1990

Parameter and Range	Range Observed	Eutrophy Points
VII. Dissolved Oxygen		
(Percent of water column with D.O. $\geq$ 0.1 ppm)		
A. 28% or less		4
B. 29% to 49%		3
C. 50% to 65%	57.14%	>2<
D. 66% to 75%		1
E. 76% to 100%		0
VIII. Light Penetration		
Secchi Disc		
A. Five feet or under	1.8 ft.	>6<
IX. Light Transmission		
(Percent at 3 ft.)		
A. 0 to 30%	13%	>4<
B. 31% to 50%		3
C. 51% to 70%		2
D. 71% and up		0
X. Total Plankton per L:		
(Vertical tow from 5 ft. to surface)		
A. Less than 4700/L		0
B. 4,701 to 9,500/L	7,609	>1<
C. 9,501 to 19,000/L		2
D. 19,001 to 28,000/L		3
E. 28,001 to 57,000/L		4
F. 57,001 to 95,000/L		5
G. More than 95,000/L		10
H. Blue-green dominance		>5 additional points<
(Vertical tow of 5 ft. through thermocline)		
A. Less than 9,500/L	148.25	>0<
B. 9,501 to 19,000/L		1
C. 19,001 to 47,000/L		2
D. 47,001 to 95,000/L		3
E. 95,001 to 190,000/L		4
F. 190,001 to 285,000/L		5
G. More than 285,000/L		10
H. Blue-green dominance		5 additional points
EUTROPHICATION INDEX		33

DONAN ENGINEERING CO. INC.

nitrate-nitrite nitrogen, total Kjeldahl nitrogen, and total phosphorus analysis. The results are summarized in Table 5.

The total Kjeldahl nitrogen at West Boggs Lake ranged from 960 mg/kg at the west leg of the lake, to 1,600 mg/kg at the northwest leg of the lake and by the dam. The Indiana Department of Environmental Management, Office of Water Management released average maximum nutrient values in sediments in their Indiana 305(b) Report of 1986-1987. It is reported that maximum background concentrations of nitrogen (Total Kjeldahl Nitrogen (TKN) only) were found to be 1,500 mg/kg. It is also reported in this report that "Sediments containing less than two times the maximum background concentration of these constituents were classified as 'uncontaminated'". This means that any values less than 3,000 mg/kg of TKN are classified as "uncontaminated". Using the Indiana 305(b) values as guidelines, the West Boggs Lake TKN sediment values are below to slightly above the maximum background ranges and well below contamination levels which means they can be classified as "uncontaminated" with respect to nitrogen.

The Total Phosphorus at West Boggs Lake ranged from 230 mg/kg at the north leg of the lake, to 430 mg/kg by the dam. It is reported that maximum background concentrations for total phosphorus were found to be 610 mg/kg (IDEM, 1986-87). It is also reported in this report that "Sediments containing less than two times the maximum background concentration of these constituents were classified as 'uncontaminated'". This means

TABLE 5

LAKE SEDIMENT ANALYSIS
WEST BOGGS LAKE

SITE #	LOCATION	DATE	TIME	NITRATE-NITRITE NITROGEN	TOTAL KJELDAHL NITROGEN	TOTAL NITROGEN	TOTAL PHOSPHORUS
1	North leg	8/9/90	10:00	60	1200	1260	230
2	Northwest leg	8/9/90	10:20	50	1600	1650	330
3	West leg	8/9/90	11:00	51	960	1011	380
LP	By the dam	8/9/90	13:00	51	1600	1651	430

* All concentrations are expressed in mg/kg of sediment

that any values less than 1,220 mg/kg of total phosphorus are classified as "uncontaminated". Using the Indiana 305(b) values as guidelines, the West Boggs Lake total phosphorus sediment values are below the maximum background ranges and contamination levels which means they can be classified as "uncontaminated" with respect to phosphorus.

3.2 Aquatic Macrophyte Vegetation

The populations of macrophytes at West Boggs Lake are minimal. A map entitled "Estimated Schematic of Shoreline Erosion and Inundated Vegetation" can be referenced in the Appendix. This map illustrates approximate locations of inundated vegetation such as tree stumps and the extent of aquatic plants. Of those species identified were sedges, bulrush (*Scirpus* sp.), cattail (*Typha latiflia*), slough grass (*Beckmannia* sp.), sago pondweed (*Potamogeton pectinatus*), cord grass (*Spartina* sp.), sweet flag (*Acorus* sp.), water horehound (*Lycopus* sp.), smartweed (*Polygonum* sp.), water primrose (*Jussiaea* sp.), button bush (*Cephalanthus occidentalis*), and black and other willows (*Salix* sp.). These species covered much less than one percent of the surface area. Mr. Steve Andrews, fisheries biologist, stated that in earlier fish management surveys, it was documented that the aquatic vegetation covered less than one percent of the lake's surface. Mr. Andrews also stated that from a fisheries viewpoint, the lake could have more vegetation.

The shoreline vegetation consisted of lowland riverbottom hardwoods. Trees identified include river birch, sycamore, cottonwood, silver maple, red cedar, red oak, black oak, walnut, tulip poplar and various hickory species.

3.3 Shoreline Erosion Survey

The result of shoreline erosion is an increased loading of sediment. Sediment is the most visible pollutant originating from nonpoint sources. Effects of excessive sediment loading on receiving waters include deterioration in aesthetic values, loss of storage capacity in reservoirs, changes in aquatic populations and their food supplies, and accumulation of bottom deposits, which impose additional oxygen demand and inhibit some advantageous benthic processes (Novotny & Chesters, 1981). The word benthic is derived from the term "benthos" which originates from the Greek word for "bottom" and broadly defines the assemblage of organisms associated with the bottom of a lake or any solid-liquid interface in aquatic systems (Wetzel, 1983).

Erosion is defined as the abrading of the land. The abrading source for shoreline erosion is wave action. A large portion of the shoreline at West Boggs Lake is suffering from erosion due in part to highly erodible soils (HEL soils) and extensive wave action. In addition, the shoreline has several severely eroded areas. The map entitled "Estimated Schematic of Shoreline Erosion and Inundated Vegetation" illustrates the various impacted areas. This is also documented in the appendixed photographs. Several trees have fallen into the lake as a result of the eroding shoreline. A few private shoreline residents have erected seawalls, rip-rap, or other materials as an attempt to curtail the erosion process. In several instances, it was documented that the rip-rap is not sufficiently protecting the shoreline.

3.4 Storm Sampling

The watershed was divided into 18 subwatersheds lettered "A" through "R" (See aerial photograph included in the Appendix). The acreage of each subwatershed is listed in Table 6. Seven of the subwatersheds were monitored during the storm sampling event, B, D, E, H, N, O, & P. These were seven of the larger subwatersheds and represented approximately 73% of the total watershed area. The remaining 27% of the watershed was assessed to generate similar runoff.

Water collected from each influent sampling point was analyzed for soluble reactive phosphorus, total phosphorus, ammonia nitrogen, nitrate nitrogen, organic nitrogen, chemical oxygen demand, and total suspended solids. The influent sampling data are presented in Table 7. The nutrient values observed are exceptionally high. The phosphorus values (TP) ranged between 0.32 and 2.80 mg/l, while the ammonia nitrogen values ranged between 0.20 to 3.40 mg/l. The total suspended solids (TSS) are moderate with the exception of inlet 5, 430 mg/l, which receives runoff from subwatershed N located in the southwest corner of the watershed. It is evident from this data that there are sources of pollution in the watershed contributing to these high concentrations of nutrients which exceed expected normal unpolluted values.

Water samples were taken from three different locations to

TABLE 6
WEST BOGGS LAKE
SUBWATERSHED PERIMERTER AND AREA MEASUREMENTS

Subwatershed ID	Perimeter linear ft.	Area acres	INLET # SAMPLED
A	27,441	283	not sampled
B	23,624	274	4
C	18,218	272	not sampled
D	45,108	1,356	1
E	40,841	1,176	2
F	10,071	100	not sampled
G	15,890	179	not sampled
H	20,056	444	3
I	18,877	149	not sampled
J	13,473	107	not sampled
K	7,213	59	not sampled
L	7,443	43	not sampled
M	28,437	471	not sampled
N	40,056	1,608	5
O	20,862	401	6
P	27,520	455	7
Q	14,644	156	not sampled
R	30,782	336	not sampled
TOTAL	410,556	7,870	
AVERAGE	22,809	437.22	

Total area represented by storm sampling = 5,714 acres or 73%

TABLE 7

WEST BOGGS LAKE
STORM SAMPLING RESULTS
All results are expressed in mg/L

	INLET 1	INLET 2	INLET 3	INLET 4	INLET 5	INLET 6	INLET 7
SUBWATERSHED	D	E	H	B	N	O	P
TOTAL ACRES	1356	1176	444	274	1608	401	455
FLOW (cfs)	43	39	3	7	45	1	8
TP	1.20	1.60	2.80	0.38	2.70	0.32	1.30
SRP	0.53	1.00	2.30	0.13	0.81	0.19	0.70
AMMONIA-N	0.80	1.70	1.60	0.30	3.40	0.20	0.90
ORG-N	1.90	2.30	2.80	1.30	2.60	1.20	2.20
NITRATE-N	0.80	1.40	1.70	0.50	0.80	0.30	1.90
COD	47	64	68	36	74	43	52
TSS	140	110	130	80	430	45	170

analyze levels of bacteria concentrations (Figure 1). The results are presented in Table 8. Both fecal coliform and fecal streptococcus were analyzed. The ratio of these two types of bacteria will yield information as to whether the majority of the bacteria is coming from human or livestock sources.

The Indiana Department of Environmental Management recently adopted new standards for bacteria in water for full body contact. The new standards use E. coli as a standard (only one type of fecal coliform which was not specifically singled out during the analysis for West Boggs Lake). However, the recently replaced standard for fecal coliform (full body contact) was 400 counts per 100 ml. Applying this standard, only one sample (North leg) exceeded that 400/100ml limit. However, this standard does not consider any of the streptococcus bacteria counts that were observed at West Boggs Lake. Contrary to popular belief, bacteria do not survive very long in an aqueous medium such as a lake. Therefore, the high bacteria counts observed by the dam in the middle of the lake are a strong indication that excessive bacteria are being washed into the lake. It is clear from the calculated ratios, that the majority of the bacteria in the represented samples collected is coming from livestock or poultry. However, only three bacteria samples were taken. If additional bacteria samples were taken around some of the lakeshore homes, bacteria ratios may suggest there is human bacteria sources as well.

BACTERIA CONCENTRATIONS
WEST BOGGS LAKE
TABLE 8

SITE #	LOCATION	DATE	TIME	FECAL COLIFORM/100 ml	FECAL STREP/100 ml	RATIO FC/FS
1	North leg	10/12/90	13:09	630	1700	0.37
2	dam location	10/12/90	13:24	160	440	0.36
3	west leg	10/12/90	13:42	320	1400	0.23

FC/FS 4.0 - Ratio greater than or equal to 4 indicates pollution derived from human wastes.

FC/FS 2-4 - Ratio between 2 and 4 suggets a predominance of human wastes in mixed pollution.

FC/FS 0.7 - Ratio less than or equal to 0.7 indicates pollution derived from livestock or poultry.

FC/FS 0.7 - 1.0 - Ratio between 0.7 and 1.0 suggests a predominance of livestock or poultry wastes in mixed pollution.

3.5 Watershed Soil and Lake Sedimentation Surveys

The type of soils present and their inherent properties throughout a watershed is the primary factor in determining the potential for excessive erosion. The soil Surveys of Daviess and Martin Counties were referenced for the distribution of soil types throughout the watershed. Mr. Bart Pitstick provided a listing of those soils that are classified as highly erodible or potentially highly erodible. Donan Engineering integrated these sources to prepare a map entitled "Distribution of Highly Erodible Soils" which can be referenced in the Appendix. Approximately 72% of the soils in the watershed are classified as highly erodible. A vast majority of the highly erodible soils are included in a crop rotation program involving conventional tillage.

The soil lost from the watershed is introduced to the lake and accumulates as sediment. Typically, accumulated sediment volumes at the inlets can be determined by setting a grid pattern in the lake, recording water depths in each grid, and comparing the data to a bathymetric map of the lake. However, only one bathymetric map was ever developed for West Boggs. This map was developed with ten-foot contours; consequently, there are only 10 foot, 20 foot and 30 foot contours present. This unfortunately does not provide any contour data for the shallower inlets of the lake which are less than 10 feet deep. Therefore, Donan Engineering could not pursue this method of sedimentation analysis.

As an alternative, Donan Engineering obtained 124 water depth levels throughout the lake as an attempt to visually assess if the lake or inlets have decreased in volume since the lake's construction in 1971. The data is presented on the map entitled "Bathymetric Mapping: Depth Reductions Due To Sedimentation" included in the Appendix. For ease of computer computations, the relative pool elevation was assigned a value of 100. Consequently, the 90 contour represents the ten foot depth, the 80 contour represents the twenty foot depth, and the 70 contour represents the thirty foot depth. All points which are marked with an X represent our 1990 measured water depth levels.

It was determined that a majority of the middle lake area has <u>not</u> experienced a significant amount of sedimentation. However, there are several inlets and "fingers" that have.

One of the first areas observed which has probably experienced sedimentation, is the northwest leg of the lake, west of St. Mary's Road. This area did not contain any original bathymetric contours which means that it was initially less than ten feet deep, but that is all we know for sure. As seen by our 1990 data point, the sounding measured 99 or 1-foot deep just west of the culvert. The remaining area was found to be filled in by sediments and vegetation.

Just south of this area, east of St. Mary's Road, we recorded soundings of 93.5 (6.5-feet deep) and 92.2 (7.8-feet deep) along the original 90 (10-foot deep) contour locations. This indicates that this area has experienced sedimentation.

Several 1990 water depths were obtained from the first major inlet west of the dam. Measurements of 94.1 (5.9-feet deep) and 94.2 (5.8-feet deep) were documented along or within the 90 contour or ten foot depth. This clearly indicates that this inlet has incurred significant amounts of sediment.

On the far west leg of the lake, west of St. Mary's Road, several 1990 water depths were obtained along the original 90 contour or ten foot depth: 92.8 (7.2-feet deep), 93.3 (6.7-feet deep), and 93.4 (6.6-feet deep). This area has also experienced excessive sediment inputs. Approximately 1000-feet west of this original ten-foot contour, soundings were recorded to be 97.3 (2.7-feet deep), 97.8 (2.2-feet deep), and 97.7 (2.3-feet deep). No original contour existed for this area, so all we know is that it was originally less than ten feet deep. However, it is suspected that this area was originally much deeper than 2.5 feet. The remaining area of the inlet is covered with vegetation and has a depth of zero.

3.6 Aerial Photograph

An aerial photograph of West Boggs and its watershed was taken on August 27, 1990 by O.A.S., Inc. located in Seymour, Indiana (included in the Appendix). This aerial photograph served a couple of purposes throughout the project. It was used in the computer modeling of the watershed by providing and verifying land uses. It was also used as a reference for assessing the extent of sedimentation of the inlets and around the lakeshore. The area of the lake was calculated from the aerial photograph and found to be approximately 575 acres. The original area of the lake was 622 acres which means that approximately 8% of the original surface area of the lake has been lost due to sedimentation activities in the inlets and around the lakeshore.

3.7 Hydrologic Analysis

The hydrology of a lake can often provide useful information in evaluating the overall water quality. A detailed and extensive study can be conducted to determine an exact water budget for a body of water. To be completely accurate, this water budget should be constructed from data collected over several years time. The water budget should detail the amount of water received at each inlet of the lake, the amount of groundwater contributed, the amount of precipitation, the amount of water discharged through each outlet, the amount of seepage losses, the amount of evapotranspiration that is occurring from the lake surface and from the surface of the aquatic vegetation, and the net inputs from all point sources throughout the watershed such as storm sewers, drainage culverts and ditches, and industrial inputs.

Since the scope of this project is not to detail an exact water budget, assumptions were made and an approximate value was calculated for the retention time or hydraulic residence time. The retention time is the length of time required for the total volume of the lake to be replaced. Our estimation utilized the following data: mean annual runoff, mean precipitation values, mean pan evaporation values, mean lake discharge values, watershed area, lake area, and lake volume. This method of estimating the retention time has proven to be very effective.

The average rainfall for the West Boggs area is approximately 42 inches (Water Resources Investigation, Open File Report 81-423). The annual average runoff was estimated to be 15.0 inches (Gerbert, Graczy, and Krug, 1985, Map included in the Appendix). Thus, the 7,870 (8,492 - 622) acre watershed would contribute 9,837.5 acre-feet of water per year. The lake would receive 2,177 acre-feet of rainfall directly. The lake would lose approximately 1,379.8 acre-feet of water per year due to evaporation from the lake surface (Indiana Department of Natural Resources, Division of Water). The lake is drawn down three feet every winter and allowed to fill back up throughout the spring, summer and fall seasons, thus an estimated value of 1,600 acre-feet was estimated as the outflow volume. This combines for an average annual net inflow of 9,035 acre-feet. The approximated average lake volume is 6220 acre-feet. Therefore, the retention time was calculated to be 0.688 years. This means that it takes 0.688 years or approximately 8 months to replace the water in the reservoir. The flushing rate is the reciprocal of the retention time. The flushing rate is the number of times the volume in the lake is replaced within a year. The flushing rate was found to be approximately 1.5. This means that about one and one-half volumes of the lake will be flushed through the lake in one year.

3.8 Human Sewage Disposal Methods

Improper human sewage disposal methods can adversely affect the water quality of a lake by loading excessive nutrients and bacteria. There are several ways to properly dispose of sewage including sewer lines or well designed and maintained septic systems. However, there are also several ways to improperly dispose of sewage which could potentially threaten the West Boggs Lake's water quality.

Mr. James Wilson, Superintendent of Loogootee Sewer Department, was contacted by Mr. Welling on January 22, 1991. He stated that the Loogootee Sewer Department has a main line that runs along the east side of and parallel to U.S. Highway 231. He stated that there are no sewer lines that service the residents around the lake since it is considered to be cost prohibitive. He also added that their current wastewater treatment plant is only designed to handle the existing waste load which is mainly collected from within Loogootee's city limits. Ms. Rosemary Harder, Martin County Sanitarian, stated to Mr. Welling on October 29, 1990, that the campers at West Boggs Park dispose of their sewage at two trailer service connections. She also stated that there is a lift station at the cabins. Mr. Wilson stated that the sewage is then conveyed to the City's main via a force main. Ms. Harder also stated that there is a sewage lift station near Stolls restaurant which is located along the shoreline of West Boggs Lake just northeast of the dam area. She then stated that this waste is also eventually directed to the Loogootee main sewer line.

The Indiana State Board of Health published Rule 410 IAC 6-8.1 entitled "Residential Sewage Disposal Systems" which became effective December 21, 1990. This regulation repeals 410 IAC 6-8 and adds 410 IAC 6-8.1 to update and clarify the requirements pertaining to the design, construction, installation, maintenance, and operation of residential sewage disposal systems. There are several items in this regulation which will impact the sewage disposal systems of the residents within the West Boggs watershed area, particularly along the lake shoreline. Of particular importance are four statements as listed below:

410 IAC 6-8.1-31(a) "No person shall throw, run, drain, seep, or otherwise dispose into any of the surface waters of this state, or cause, permit, or suffer to be thrown, run, drained, allowed to seep, or otherwise disposed into such waters, any organic or inorganic matter from a dwelling or residential sewage disposal system that would cause or contribute to a health hazard or water pollution."

410 IAC 6-8.1-31(c) "All residential sewage disposal systems utilizing sanitary privies shall conform to Indiana state board of health bulletin SE 11, `The Sanitary Vault Privy,' 1986 Edition."

410 IAC 6-8.1-31(d) "Any dwelling which is not connected, or cannot be connected, to a sanitary sewerage system and which does not utilize a sanitary privy for its residential sewage disposal system shall be provided with a residential sewage disposal system which includes a septic tank and a soil absorption system that has not failed."

410 IAC 6-8.1-31(e) "...A temporary sewage holding tank shall not be used as a primary means of residential sewage disposal except where necessary to prevent continued discharge of wastewater from a failed existing system. A temporary sewage holding tank may be used as follows:

1.) As a temporary storage facility for no more than one (1) year where occupancy of the home must continue while the system is being renovated.

2.) Where such facility is owned and operated temporarily by a conservancy district, sewer district, private utility, or municipality as a part of its sewage disposal plan or for no more than one (1) year while connection to sanitary sewer is being secured."

In summary, these quotes are stating that the only approved ways to dispose of sewage, aside from sewers, is the proper installation of a sanitary vault privy or the proper installation of a non-failing septic tank with a soil absorption system. Temporary sewage holding tanks or any other system, without approved written consent from the Commissioner, are no longer allowed to be used by law and should be replaced by an acceptable system.

3.9 Watershed Land Use Analysis

Mr. Bob Smolik, Superintendent of West Boggs Park, and Mr. Bart Pitstick, conducted the initial land use surveys and recorded the land uses on a copy of the aerial photograph. Records of previous surveys and aerials were referenced at the SCS office and current field surveys were conducted to assign land uses throughout the West Boggs watershed. Donan Engineering then used a computer planimeter to evaluate the area of each land use. The land uses were then summed according to similar categories. The results of the survey are presented in Table 9.

A majority of the watershed is farmland. Approximately 44% of the watershed area was found to be in crops; after adding pastures and wheat fields, the total farmland was totaled to be about 68%. Forrest lands covered approximately 14% of the watershed area. Residential, wildlife areas, coal mines, grass areas, turkey ranges, wetlands, ponds, Water and Sediment Control Basins (WASCOBS), lagoons, commercial, industrial, and feed lots make up the remaining 18% of the land uses.

Table 9
WEST BOGGS LAKE
LAND USES

	ACRES	PERCENT
CROP-WHEAT	210.3	2.67%
CROP-CORN	3,016.0	38.32%
CROP-BEANS	210.5	2.67%
Subtotal Crops	3436.8	43.67%
PASTURE	1,908.0	24.24%
Subtotal Farmland	5,344.8	67.91%
FOREST	1,110.4	14.11%
RESIDENTIAL	423.7	5.38%
WILDLIFE	350.5	4.45%
COAL MINE	303.7	3.86%
GRASS	134.5	1.71%
TURKEY RANGE	69.2	0.88%
WETLAND	26.2	0.33%
PONDS	34.8	0.44%
LAGOONS	1.8	0.02%
WASCOBS	1.3	0.02%
COMMERCIAL	7.2	0.09%
INDUSTRIAL	1.5	0.02%
FEED LOTS	60.4	0.77%
TOTAL	7,870.0	100.00%
LAKE AREA	622.0	
TOTAL AREA	8,492.0	

Section 4. COMPUTER MODELING

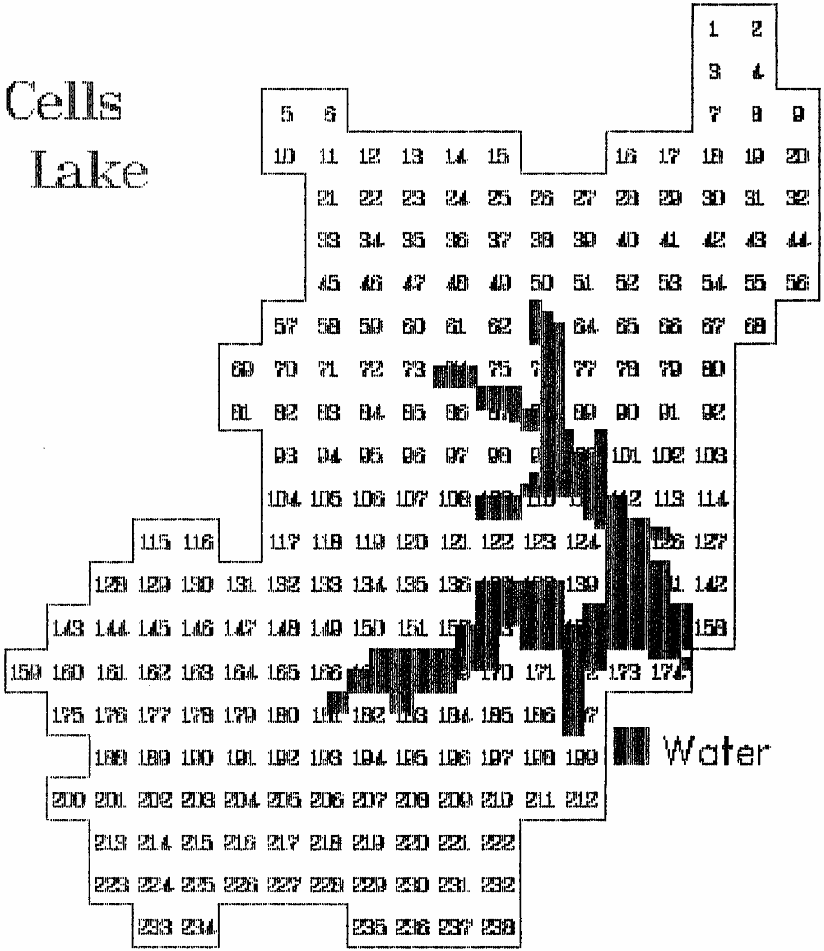
4.1 Introduction

The program used for modeling sediment and nutrient loading into West Boggs Lake was the Agricultural Non-Point Source Pollution Model (AGNPS). AGNPS was developed by R.A. Young and C.A. Onstad at the USDA North Central Soil Conservation Research Laboratory in Morris, Minnesota.

The lake and its watershed were sectioned into 40-acre cells for analysis (Figure 4). The majority of these 40-acre cells appeared to have highly variable conditions within their boundaries whereby it became necessary to further divide them into smaller 10-acre cells. These 10-acre cells were considered to be more manageable and the data input for them is apt to better reflect actual field conditions. The analysis was based on the examination of variables inherent to soils existing in the watershed including land slope, slope shape and length factors, soil erodibility, and texture characteristics. Additional variables which vary according to management practices within the watershed were also sources of data for the model. Included were runoff coefficients, channel slopes, channel roughness coefficients, cropping factors, practice factors, surface condition constants, and fertilization practices. The existence and apparent management of animal feeding lots, as well as other point sources, were examined. The sediment and nutrient loading were modeled using a theoretical 10 year/24 hour storm event of 4.5 inches with an

FIGURE 4

Watershed Cells
West Boggs Lake



energy-intensity value of 125.

Nutrient loading values, chemical oxygen demands and watershed soil losses were evaluated. The control of nutrient loading to a lake is very important as was discussed in Sections 3.0-7 and 3.0-8. Phosphorus is responsible for limiting primary production in most freshwater systems and is consequently the principal focus in nutrient studies. Nitrogen, however, can also play a major role in plankton metabolism and can expedite the eutrophication process within a lake. Chemical Oxygen Demand (COD) is another important parameter which can adversely affect the quality of a lake. COD is generally defined as oxidizable chemical compounds that remove oxygen from the water. Sediment is the most visible pollutant originating from nonpoint sources. After the soil has been transported to the lake by surface runoff, it is deposited in the inlets and along the shoreline. Effects of excessive sediment loading on receiving waters include deterioration in aesthetic values, loss of storage capacity in reservoirs, changes in aquatic populations and their food supplies, and accumulation of bottom deposits, which impose additional oxygen demand and inhibit some advantageous benthic processes (Novotny & Chesters, 1981). A negative economic impact is incurred by the farmer that loses the soil and nutrients.

4.2 Modeling Results

4.2-1 Nutrient Loading

There are two forms of nutrients that are modeled by AGNPS, soluble and sediment associated. The soluble nutrient values demonstrate the concentration of dissolved nutrients in the storm water when leaving a cell during a particular storm event. These values are reported in milligrams of nutrients dissolved per liter of water or parts per million (ppm). The sediment associated nutrient values represent that portion of a particular nutrient which leaves the cell attached to soil colloids suspended in and transported by the runoff during this particular storm event. These values are reported in pounds of a nutrient lost per acre of land.

The soluble nutrient data can been seen in Figure 5. This figure displays those cells that were in excess of 10 ppm of Phosphorus and/or Nitrogen. There are two cells that exceed this limit for Phosphorus, and nine cells or portions of cells that exceed this limit for Nitrogen.

The sediment associated nutrient data can been seen in Figure 6. This figure displays those cells that lost in excess of 5 pounds per acre (lb./A) of Phosphorus as well as cells that lost in excess of 10 lb./A of Nitrogen during this storm event. Of the 238 cells comprising the watershed, 29 cells ,or portions thereof, exhibited loading rates of more than 5 lb./A of sediment associated phosphorus. Nearly half of the cells (or at least a subdivision of nearly half of the cells) in the watershed exceeded the 10 lb./A limit established for

FIGURE 5

Soluble Nutrient Loading
West Boggs Lake
Existing

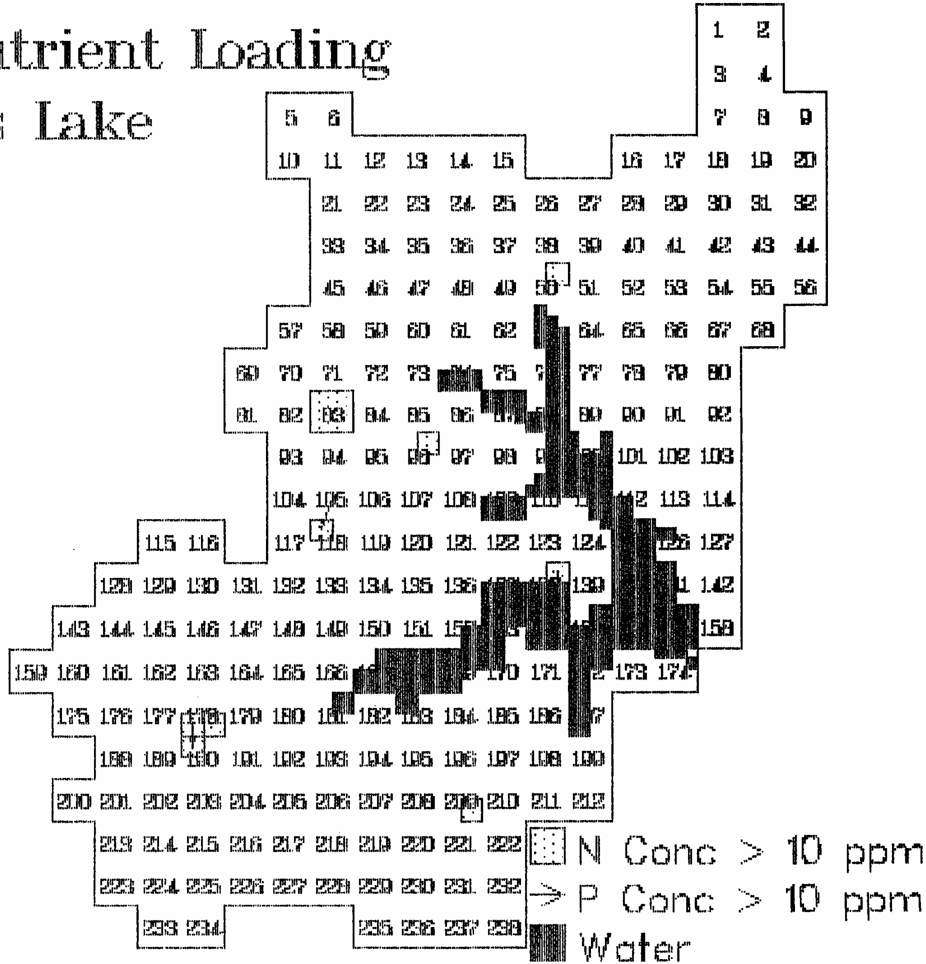
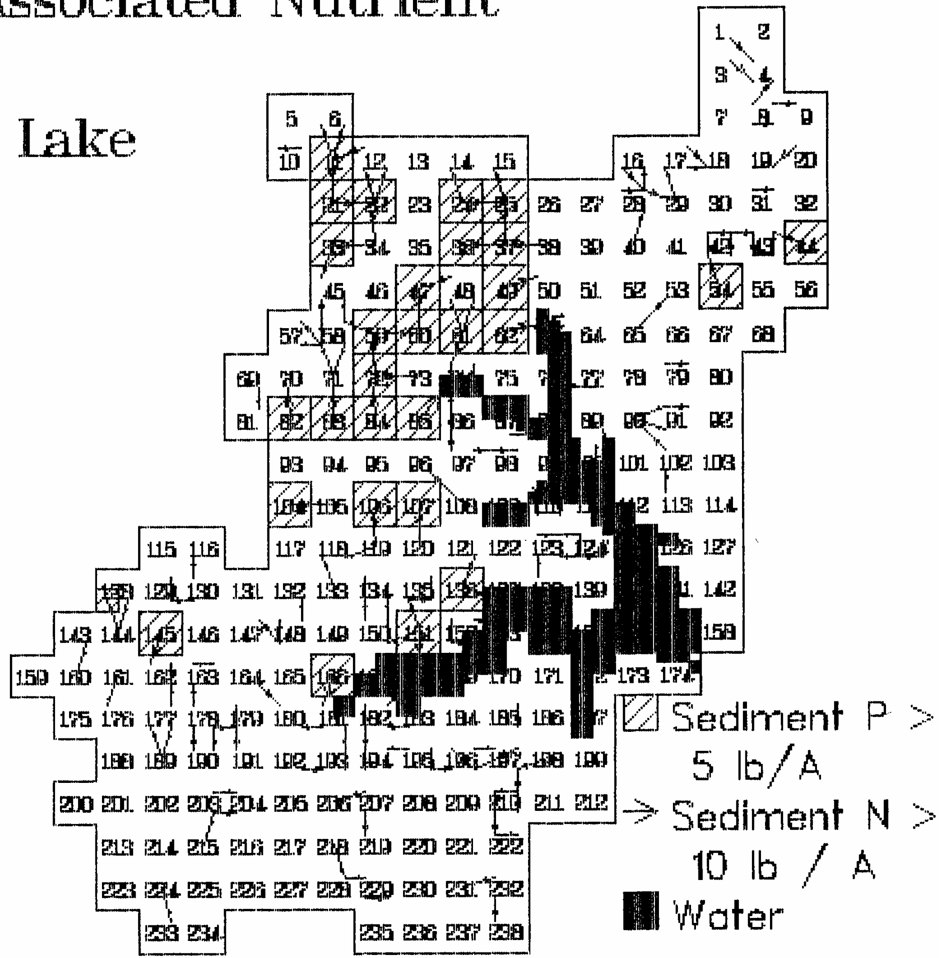


FIGURE 6

Sediment Associated Nutrient Loading West Boggs Lake Existing



nitrogen. All of the 29 cells that had high levels of sediment associated phosphorus leaving the cells also exceeded the nitrogen limit.

The chemical oxygen demand (COD) data is displayed in Figure 7. This graph indicates high concentrations or mass loads for COD in nine cells.

4.2-2 Soil Loss

The AGNPS model will calculate how many tons of soil are lost per acre of land for this storm event. Many references were located and contacted in an attempt to define an excessive erosion value for different types of soils. All the values however, were reported in units of mass/area/time such as tons/acre/year. No equations existed to corollate these estimates to single storm events. Mr. Bruce Lucord of the United States Department of Agriculture, North Central Soil Conservation Research Laboratory of Morris, Minnesota was involved in the writing of the AGNPS program. He stated that as a general rule, the USDA considers a loss of 5 tons/acre for a 25 year/24 hour storm event as excessive erosion. Donan Engineering then modeled a lake watershed on an earlier project for a 25 year/24 hour storm event and located those cells that lost in excess of 5 tons/acre. A comparison was then modeled between the 25 year and 10 year events and found that setting a loss criteria of 3.7 tons/acre coincides with the same cells for the 10 year event as 5 tons/acre did for the 25 year event. Consequently, 3.7 tons/acre is the value chosen to represent excessive erosion. Figure 8 illustrates 160 cells

FIGURE 7 West Boggs Lake

High COD

Existing

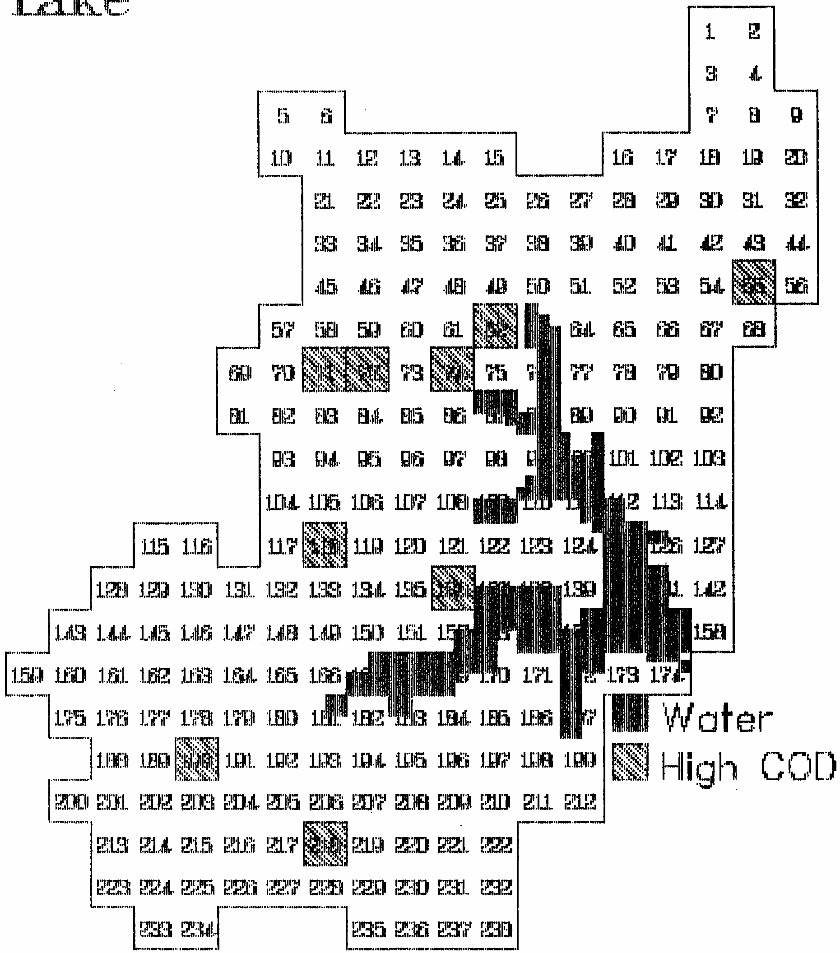
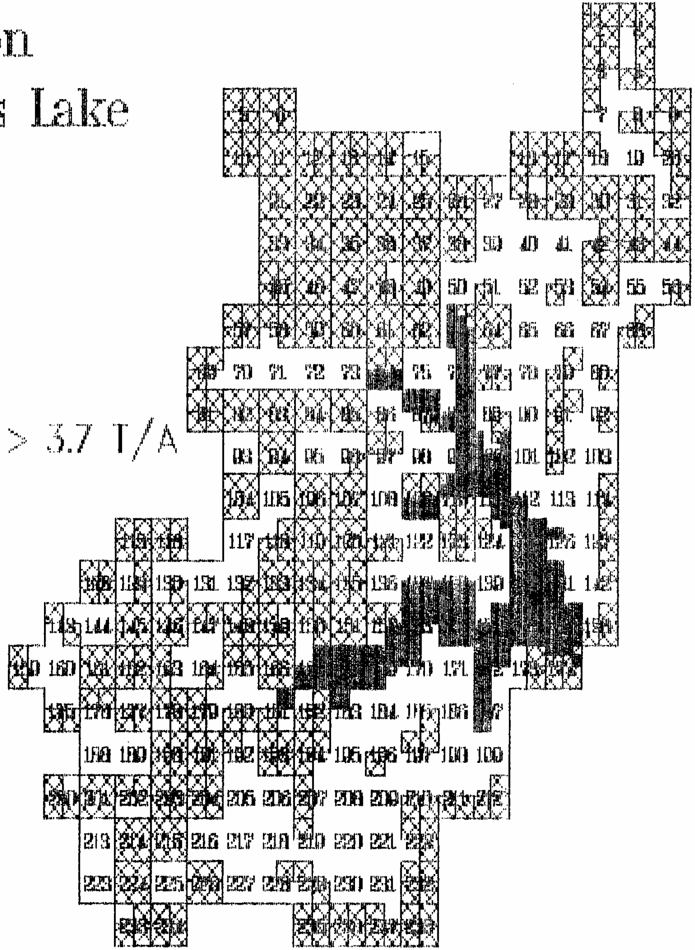


FIGURE 8

Soil Erosion

West Boggs Lake

Existing



Water

Soil Erosion > 3.7 T/A

that lost at least 3.7 tons/acre for this modeled 10 year/24 hour event. The values of nutrients and sediments leaving at the watershed outlet are displayed in Table 10. The total sediment yield for this storm event is calculated to be 1382.5 tons.

4.3 Modeling Treatments

The fundamental reason for computer modeling is to theorize the results of some type of change to the present case of events. In AGNPS, changes that can be implemented in a watershed to create a more desirable outcome are typically related to alternate landuses and/or alternate management practices. In the West Boggs Lake study, four treatments were developed and modeled. The treatments proposed for the watershed are considered to be realistic adjustments to the management practices that currently prevail. Since it would serve no purpose to speculate on what is not attainable, the practices proposed are limited to changes in the management regime that are economically feasible and are likely to have positive results even if only partially implemented. The objectives of the treatments, in order of priority, are to 1) reduce the incidence of excessive soil loss from all cells in the watershed, 2) reduce the sediment associated nutrient loading to the lake, and 3) reduce the feedlot associated soluble Nitrogen, soluble Phosphorous and COD that are contributing to the nutrient loading of the lake.

Interviews with farmers in the watershed, data from local SCS representatives, and observations by Donan Engineering

TABLE 10

Watershed Summary

Watershed Studied	WEST BOGGS LAKE
The area of the watershed is	8530 acres
The area of each cell is	40.00 acres
The characteristic storm precipitation is	4.50 inches
The storm energy-intensity value is	125

Values at the Watershed Outlet

Cell number	174 240
Runoff volume	2.7 inches
Peak runoff rate	3829 cfs
Total Nitrogen in sediment	0.85 lbs/acre
Total soluble Nitrogen in runoff	1.59 lbs/acre
Soluble Nitrogen concentration in runoff	2.63 ppm
Total Phosphorus in sediment	0.42 lbs/acre
Total soluble Phosphorus in runoff	0.28 lbs/acre
Soluble Phosphorus concentration in runoff	0.46 ppm
Total soluble chemical oxygen demand	65.63 lbs/acre
Soluble chemical oxygen demand concentration in runoff	109 ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.30	0.00	54	20	531.79	0.16	1370.7
SILT	0.48	0.00	0	0	0.65	0.00	1.7
SAGG	2.99	0.00	0	0	0.71	0.00	1.8
LAGG	1.86	0.00	0	0	2.43	0.00	6.3
SAND	0.36	0.00	0	0	0.76	0.00	2.0
TOTAL	5.99	0.00	3	1	536.34	0.16	1382.5

indicate the vast majority of the tillable soils in the watershed are managed by farmers who practice a basic five (5)-year crop rotation plan. These crops are produced nearly exclusively by conventional tillage methods. Typically, this rotation includes two years of row crops (predominantly corn), one year small grain (wheat), and two years of grass and legume hay. Three of the four treatments proposed involve modifications to the crop rotation plan while the fourth involves feedlot design. The four treatments suggested include:

1) Use a No-till system to produce the second year corn crop in those cells which have soil loss > 3.7 Tons/Acre.
2) Use a No-till system exclusively for the two years of corn production in those cells which still have soil loss > 3.7 Tons/Acre after Treatment 1.
3) Remove the cells which still have soil loss > 3.7 Tons/Acre after Treatment 2 from the crop rotation plan and establish them as permanent meadow.
4) Maintain a buffer strip of permanent meadow no less that 300 feet between runoff channels and feedlots that significantly contribute to soluble nitrogen, soluble phosphorus, and/or COD loading of the lake.

4.3-1 <u>Treatment One</u>

With the existing management regime, the computer model designated 160 cells as having soil erosion > 3.7 Tons/ acre.

For those cells which have been subdivided, the excessive erosion occurred in at least one 10-acre subdivision, however many cells had more than one subdivision designated. Table 10 summarizes the results of a 4.5 inch rain in a 24-hour period in this watershed and indicates the total soil loss of 1382.5 Tons for a precipitation event of that magnitude. The focus of the first treatment is to reduce that loss.

Treatment One is to simulate utilization of No-till in producing corn in the second year of the crop rotation program. Only those cells (or subcells) which had greater than 3.7 Tons/Acre of soil loss were subjected to the treatment. The use of No-till was simulated by changing one parameter of the data file. The Cropping Factor is the soil loss ratio corresponding to the appropriate period of the growing season. This ratio is of soil loss from cropland to corresponding loss from continuous fallow. A high Cropping Factor then indicates susceptibility to erosion as the soil surface is exposed and vulnerable.

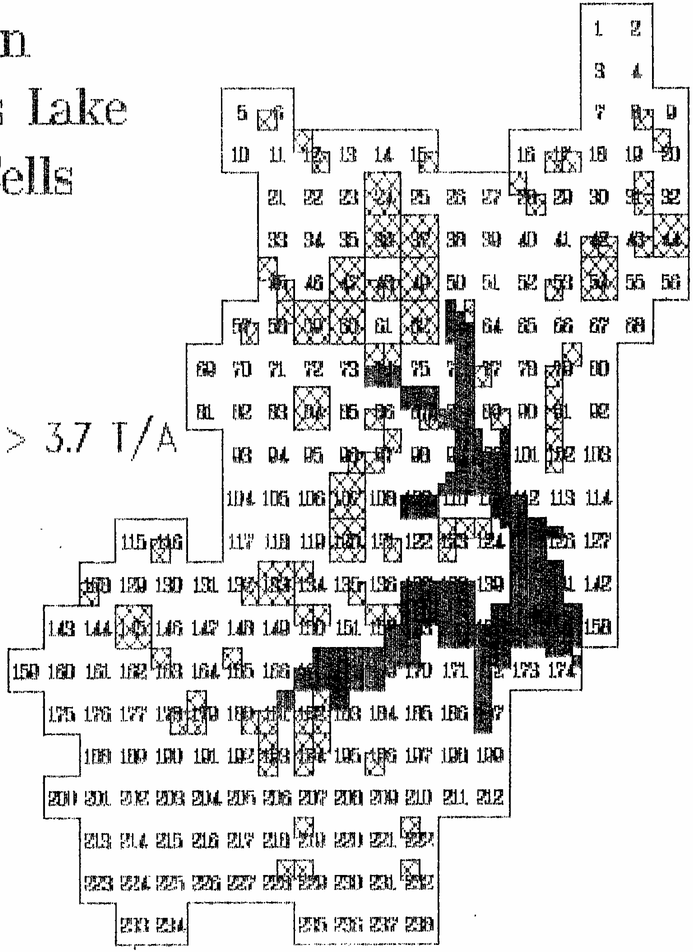
Under conventional tillage systems, the average soil loss for acreage in the practiced five-year rotation plan was calculated to be approximately 0.43 when watershed conditions were observed in February 1991. If only the second year corn crop had been produced under a No-till system, the average soil loss ratio would be reduced to 0.15 during that time period. The treatment then consists of changing the Cropping Factor of those cells with > 3.7 T/A soil loss to a new value of 0.15 in the data file of the computer model. This editing is considered to be quite conservative as other parameters including the SCS curve number, the Manning's roughness coefficient, and the surface condition constant could likewise be adjusted to indicate a more dramatic response. The reduction in soil loss resultant from this corrective measure is sizable. Figures 8 and 9 can be compared to see the number of cells that have had their soil loss reduced to an acceptable level. Sixty-six of the 160 cells remain to have a soil loss problem, however the total soil loss for the design storm event has been reduced from 1382.5 tons to 511.0 tons.

As discussed in Section 3.61A, sediment associated nutrient loading is a direct function of soil loss as the soil colloids serve as a transporting medium for the nutrients. Treatment One therefore also dramatically reduced the number of cells that contributed excessive amounts of sediment associated Nitrogen and Phosphorous to the lake. The existing conditions now suggest there are 111 cells loosing greater than 10 lb./A of sediment nitrogen and 28 cells with sediment phosphorus loss greater than 5 lb./A.

After implementation of Treatment One, the number of cells with excess loss of sediment nitrogen is reduced to 12 and those remaining to have excess loss of sediment phosphorus are 4 (Figure 10). Table 10 summarizes the loading values on a per acre basis for the entire watershed in the existing condition, while Table 11 condenses the same data after Treatment One. Note that the sediment nitrogen average is 0.85 lb./A before and 0.38 lb./A after. The respective values for sediment

FIGURE 9

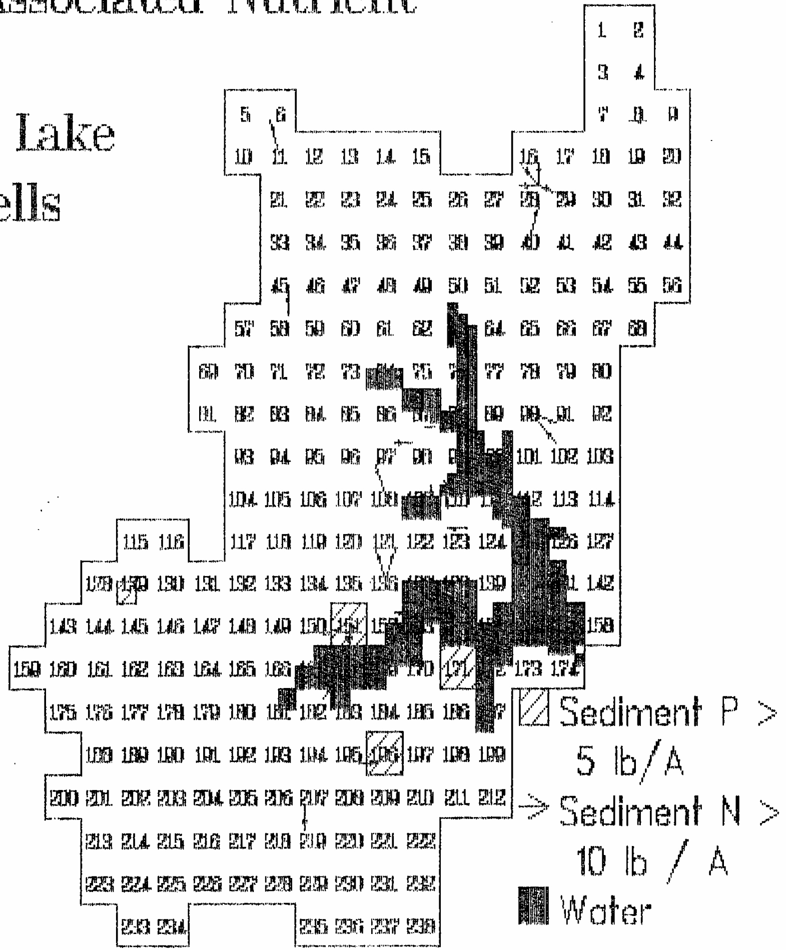
Soil Erosion West Boggs Lake Problem Cells in No-til 2nd Year



■ Water
⊠ Soil Erosion > 3.7 T/A

FIGURE 10

Sediment Associated Nutrient Loading
West Boggs Lake
Problem Cells
in No-til
2nd Year



phosphorus are 0.42 lb./A and 0.19 lb./A.

Treatment One (and subsequent Treatments Two and Three) emphasized soil loss and associated sediment nutrient loading and made no attempt to reduce the soluble nutrient loading impacting the lake. Figures 5 and 11 and Tables 10 and 11 support the premise that indeed Treatment One had no measurable effect on soluble nutrient loading.

4.3-2 <u>Treatment Two</u>

A further measure to reduce the soil and sediment associated nutrient loss would include the exclusive use of No-till in row crop production in the cells that continue to exhibit greater than 3.7 Tons/A of soil loss after Treatment One.

Treatment Two would apply only to those sixty-six cells which persist to have excessive soil loss. While Treatment One involved use of No-till methodology in producing the second corn crop in the rotation, Treatment Two would eliminate by and large the moldboard plow as a routine tillage tool in those cells. No-till equipment would be used exclusively for both corn (or soybean) crops followed by one year of wheat and two years of hay.

Simulation of Treatment Two was accomplished by again lowering the cropping factor in the sixty-six problem cells. The use of No-till in establishing the first year corn crop, instead of moldboard plowing the hayfields, reduces the cropping factor for the five year rotation period from 0.15 to 0.07. Figure 12 depicts the results in that thirty-five cells

FIGURE 11

Soluble Nutrient Loading
West Boggs Lake
Problem Cells
in No-til
2nd Year

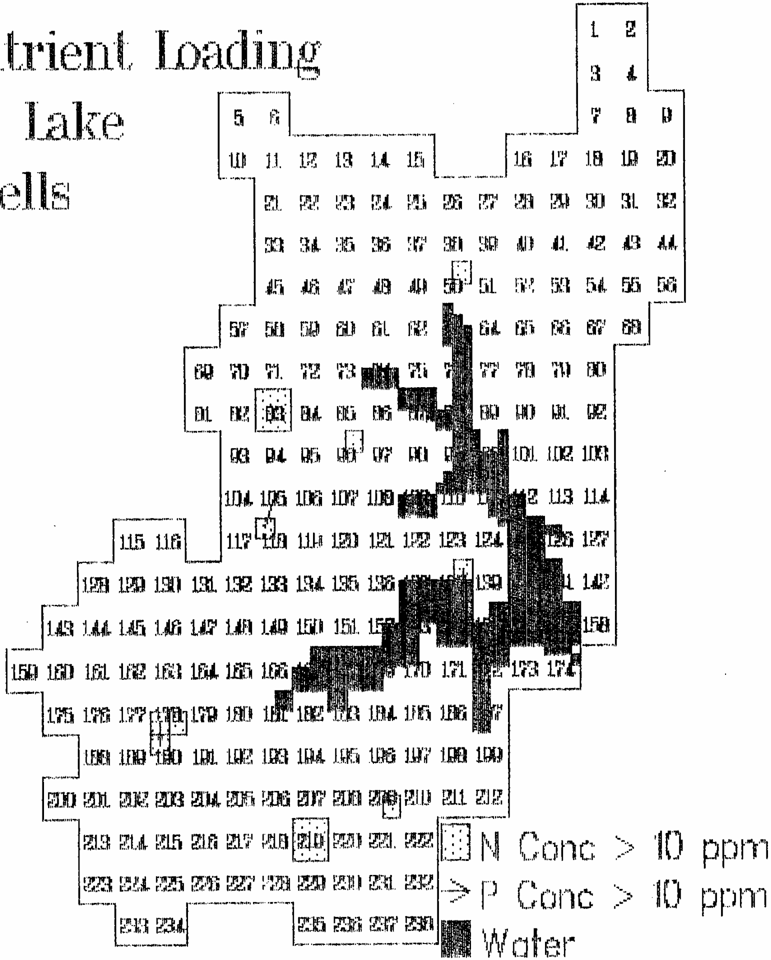


TABLE 11

Watershed Summary

Watershed Studied	WEST BOGGS LAKE
The area of the watershed is	8530 acres
The area of each cell is	40.00 acres
The characteristic storm precipitation is	4.50 inches
The storm energy-intensity value is	125

Values at the Watershed Outlet

Cell number	174 240
Runoff volume	2.7 inches
Peak runoff rate	3829 cfs
Total Nitrogen in sediment	0.38 lbs/acre
Total soluble Nitrogen in runoff	1.59 lbs/acre
Soluble Nitrogen concentration in runoff	2.63 ppm
Total Phosphorus in sediment	0.19 lbs/acre
Total soluble Phosphorus in runoff	0.28 lbs/acre
Soluble Phosphorus concentration in runoff	0.46 ppm
Total soluble chemical oxygen demand	65.63 lbs/acre
Soluble chemical oxygen demand concentration in runoff	109 ppm

Sediment Analysis

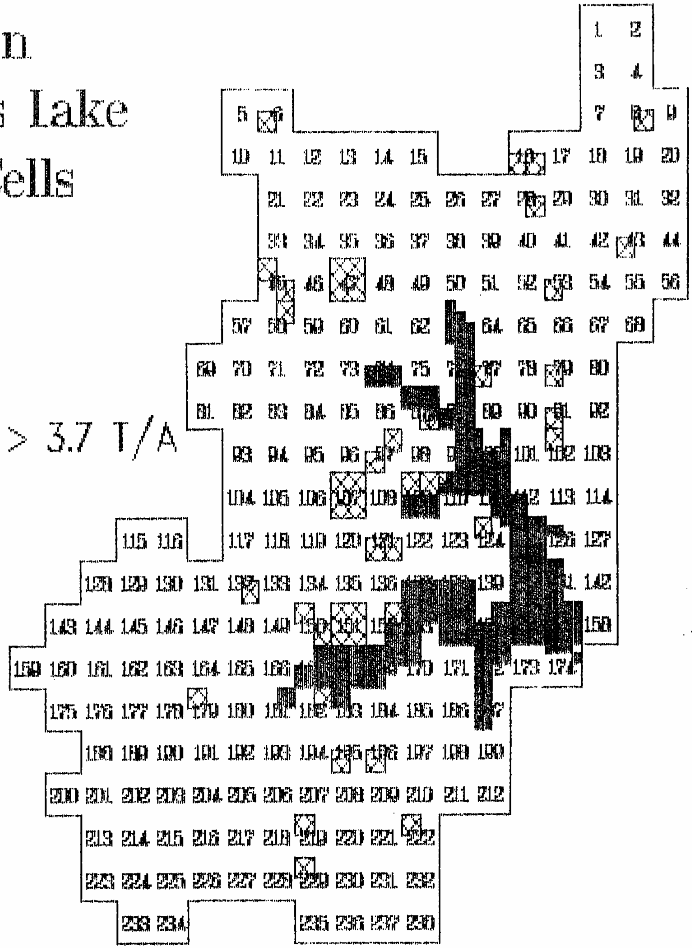
Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.11	0.00	54	20	193.71	0.06	499.3
SILT	0.17	0.00	0	0	0.64	0.00	1.7
SAGG	1.08	0.00	0	0	0.71	0.00	1.8
LAGG	0.67	0.00	0	0	2.43	0.00	6.3
SAND	0.13	0.00	0	0	0.76	0.00	2.0
TOTAL	2.15	0.00	3	1	198.25	0.06	511.0

FIGURE 12

Soil Erosion West Boggs Lake Problem Cells in No-til

Water

Soil Erosion > 3.7 T/A



are no longer flagged as having soil loss greater than 3.7 Tons/A. While thirty-one cells are still designated as problem cells, Tables 11 and 12 illustrate that the overall sediment yield to the lake has dropped from 511.0 Tons to 409.8 Tons.

As is to be expected, sediment associated Nitrogen and Phosphorous loading is also further reduced in Treatment Two. Figures 10 and 13 indicate the number of cells with excess nitrogen loading has gone from twelve to two by changing tillage practices. Likewise, the incidence of excess phosphorus loading has been reduced from four cells to two cells. Tables 11 and 12 show that, on a per acre basis, sediment nitrogen has gone from 0.38 lb. to 0.32 lb. The reduction in sediment phosphorus is from 0.19 lb./A to 0.16 lb./A. While these reductions appear to be slight, one needs to keep in mind the average applies to all 8,530 acres (as estimated by AGNPS) in the watershed; not just the sixty-six cells or partial cells involved in Treatment Two.

As predicted, no changes occurred in the soluble nutrient loading to the lake as a result of Treatment Two being implemented (Figure 14).

4.3-3 <u>Treatment Three</u>

Computer Modelling has suggested the soil loss to the total watershed (during a 4.5-inch rain occurring in a 24-Hr period) can be reduced from 1382.5 Tons to 409.8 tons by changing the management practices on certain areas. These changes can reduce the soil loss during that precipitation event by 70% and are capable of being implemented without reducing the

TABLE 12

Watershed Summary

Watershed Studied	WEST BOGGS LAKE	
The area of the watershed is	8530	acres
The area of each cell is	40.00	acres
The characteristic storm precipitation is	4.50	inches
The storm energy-intensity value is	125	

Values at the Watershed Outlet

Cell number	174	240
Runoff volume	2.7	inches
Peak runoff rate	3829	cfs
Total Nitrogen in sediment	0.32	lbs/acre
Total soluble Nitrogen in runoff	1.59	lbs/acre
Soluble Nitrogen concentration in runoff	2.63	ppm
Total Phosphorus in sediment	0.16	lbs/acre
Total soluble Phosphorus in runoff	0.28	lbs/acre
Soluble Phosphorus concentration in runoff	0.46	ppm
Total soluble chemical oxygen demand	65.63	lbs/acre
Soluble chemical oxygen demand concentration in runoff	109	ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.09	0.00	54	19	154.44	0.05	398.1
SILT	0.14	0.00	0	0	0.64	0.00	1.6
SAGG	0.86	0.00	0	0	0.71	0.00	1.8
LAGG	0.53	0.00	0	0	2.43	0.00	6.3
SAND	0.10	0.00	0	0	0.76	0.00	2.0
TOTAL	1.72	0.00	3	1	158.98	0.05	409.8

FIGURE 13

Sediment Associated Nutrient Loading West Boggs Lake Problem Cells in No-til

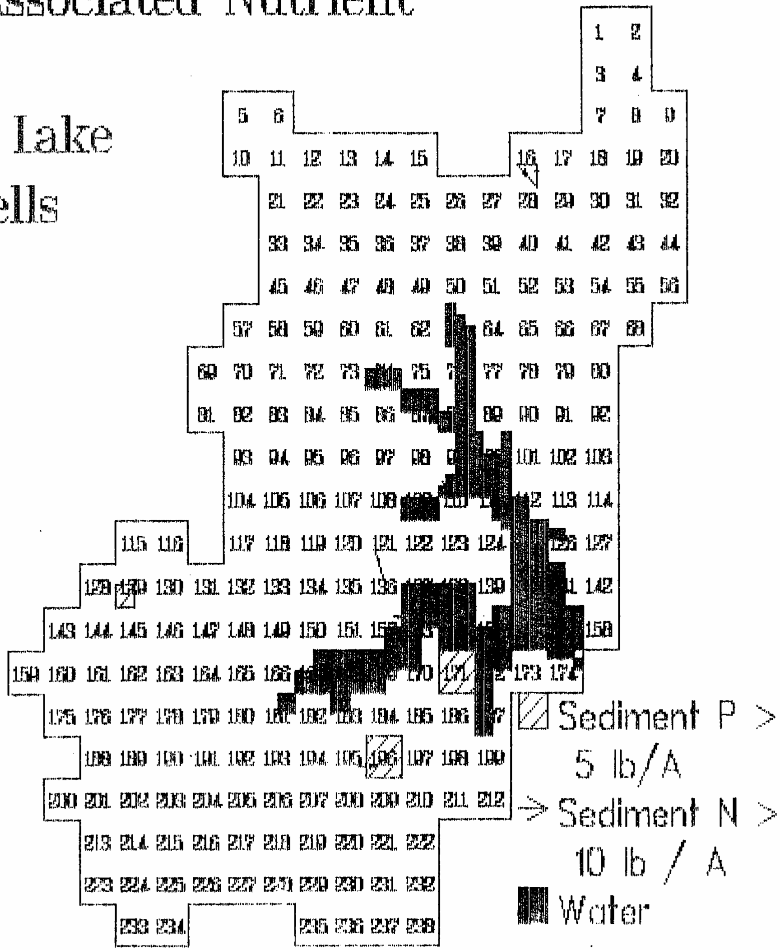
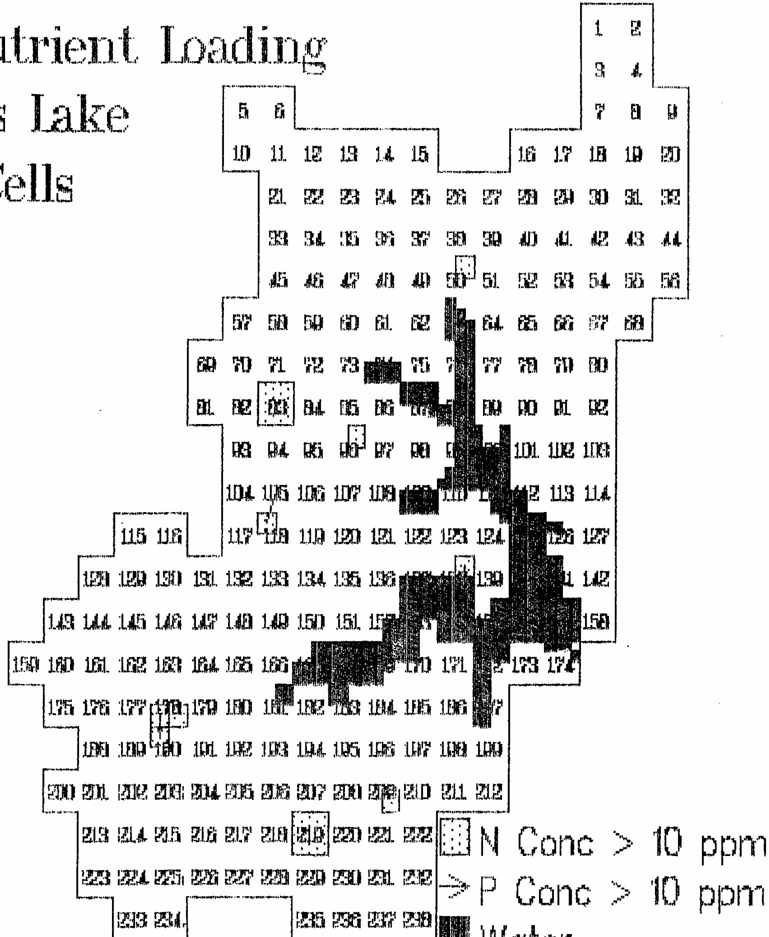


FIGURE 14

Soluble Nutrient Loading West Boggs Lake Problem Cells in No-til



marketable production of the land. To this point, alternative landuses have not been required and the treatments have consisted only of using No-til in cells that have excessive soil losses.

The third treatment proposed involves removing certain acres from row crop production. The thirty-one cells which still have portions of their acreage losing more than 3.7 Tons of soil per acre, are areas that would be better suited to an alternate landuse. The area of the portions of these thirty-one cells is approximately 450 acres or 5.3% of the watershed.

One alternative to the five-year crop rotation plan for these areas is to establish the land as permanent meadow. Permanent meadow was chosen in an attempt to realistically <u>minimize</u> the soil loss from those cells. Other landuses that would be less dramatic and that could cause less financial hardship might include pasture and hay, forest, and wildlife habitat.

The simulation for Treatment Three involves more than an adjustment to the cropping factors of the remaining problem cells. Parameters that are a function of landuse are the SCS curve number, the Manning's coefficient, the cropping factor, the surface condition constant, the fertilization level and availability factor, and the Chemical Oxygen Demand factor. Table 13 illustrates the changes that were made to the data file to model the permanent meadow treatment. Figure 15 demonstrates that after implementation of all three treatments,

TABLE 13
TREATMENT THREE
PARAMETERS OF CELLS WITH EXCESSIVE SOIL LOSS
AFTER TREATMENT TWO

CELL #	RCN	MANN COEFF	C-FACTOR	SURF COND	FERT	% AVAIL	COD
6-300	85	0.048	0.07	0.05	2	5	170
8-400	85	0.075	0.07	0.05	2	5	170
16-300	85	0.075	0.07	0.05	2	5	170
16-400	85	0.075	0.07	0.05	2	5	170
28-400	85	0.13	0.07	0.05	2	5	170
43-300	82	0.04	0.07	0.29	2	50	80
45-100	82	0.13	0.07	0.29	2	50	80
45-400	85	0.075	0.07	0.05	2	5	170
47	85	0.04	0.07	0.05	2	5	170
53-300	85	0.075	0.07	0.05	2	5	170
58-200	85	0.13	0.07	0.05	2	5	170
77-300	85	0.13	0.07	0.05	2	5	170
79-300	85	0.04	0.07	0.05	2	5	170
87-430	85	0.075	0.07	0.05	2	5	170
87-440	85	0.075	0.07	0.05	2	5	170
91-300	82	0.13	0.07	0.29	2	50	80
97-200	85	0.048	0.07	0.05	2	5	170
97-300	74	0.13	0.07	0.22	1	100	60
102-100	82	0.04	0.07	0.29	2	50	80
107	85	0.075	0.07	0.05	2	5	170
109-100	86	0.048	0.07	0.01	1	100	60
109-200	86	0.05	0.07	0.01	1	100	60
110-110	86	0.05	0.07	0.01	1	100	60
121-300	85	0.075	0.07	0.05	2	5	170
121-400	85	0.048	0.07	0.05	2	5	170
124-100	85	0.048	0.07	0.05	2	5	170
132-300	85	0.04	0.07	0.01	0	100	80
150-100	85	0.04	0.07	0.05	2	5	170
150-400	74	0.13	0.07	0.22	1	100	60
151	85	0.075	0.07	0.05	2	5	170
152-200	85	0.048	0.07	0.05	2	5	170
179-100	85	0.04	0.07	0.05	2	5	170
182-200	85	0.075	0.07	0.05	2	5	170
195-300	70	0.04	0.07	0.59	0	100	65
196-300	91	0.033	0.07	0.22	2	5	170
219-100	85	0.075	0.07	0.05	2	5	170
222-100	91	0.048	0.07	0.22	2	5	170
229-100	85	0.048	0.07	0.05	2	5	170
	PARAMETERS USED TO SIMULATE PERMANENT MEADOW						
ALL	71	0.3	0.01	0.59	0	0	60

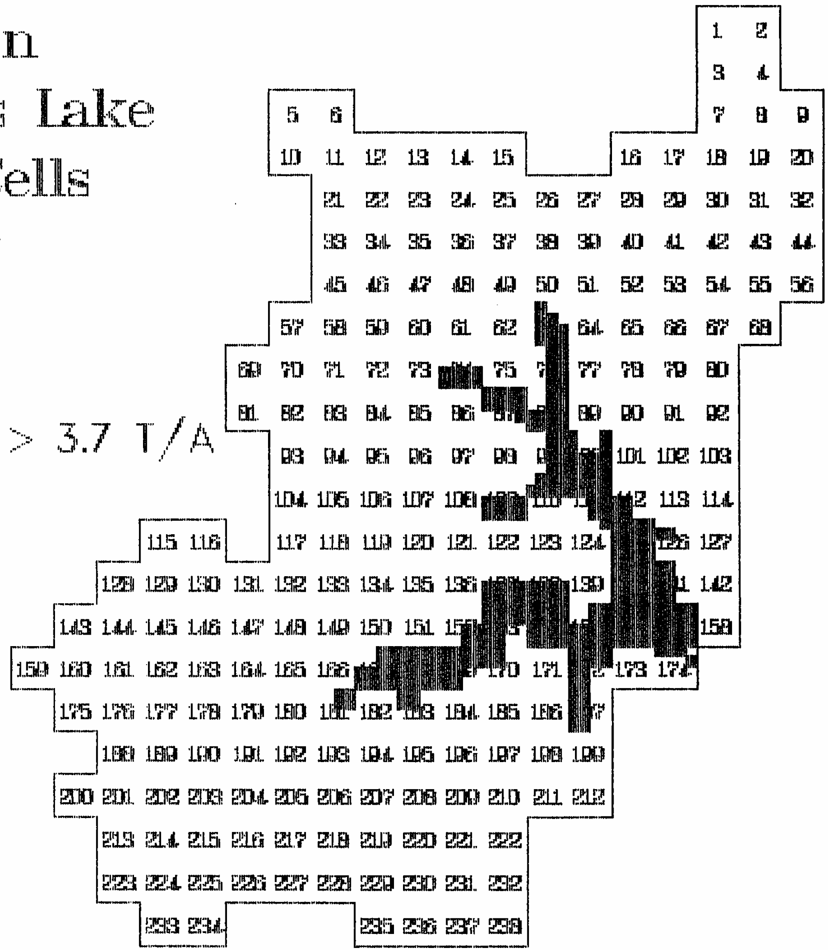
DONAN ENGINEERING CO. INC.

FIGURE 15

Soil Erosion West Boggs Lake Problem Cells in Meadow

Water

Soil Erosion > 3.7 T/A



soil loss has been reduced to acceptable levels throughout the watershed. Referring to Tables 12 and 14 indicates the total soil loss to the watershed has dropped from 409.8 tons to 348.3 tons as a result of implementing Treatment Three.

Sediment associated nutrient loading to the lake has also been reduced in problem cells due to Treatment Three. Figure 16 illustrates that all problem cells have had sediment associated Nitrogen and Phosphorous loading reduced to tolerable levels. Tables 12 and 14 indicate that total nitrogen in sediment fell from 0.32 lb./A to 0.28 lb./A and total phosphorus in sediment went from 0.16 lb./A to 0.14 lb./A directly attributable to Treatment Three.

Figure 17 reflects that once again, soluble nutrient loading was not affected by this treatment.

4.3-4 Treatment Four

Domestic livestock production is widespread in the West Boggs Lake watershed. Many producers have extensive state-of-the-art confinement facilities while others are engaged in low investment, high labor operations. Most producers compromise with both methods. AGNPS modelling recognizes livestock feedlots as a point source of potential pollution in a watershed and attempts to rate the feedlots according to that potential.

The potential to contribute significant quantities of pollutants is dependent upon the feedlot size and runoff coefficient, areas of the feedlot that are roofed, and areas upgradient to the feedlot that drain in and through the lot.

TABLE 14

Watershed Summary

Watershed Studied	WEST BOGGS LAKE
The area of the watershed is	8530 acres
The area of each cell is	40.00 acres
The characteristic storm precipitation is	4.50 inches
The storm energy-intensity value is	125

Values at the Watershed Outlet

Cell number	174 240
Runoff volume	2.6 inches
Peak runoff rate	3750 cfs
Total Nitrogen in sediment	0.28 lbs/acre
Total soluble Nitrogen in runoff	1.53 lbs/acre
Soluble Nitrogen concentration in runoff	2.58 ppm
Total Phosphorus in sediment	0.14 lbs/acre
Total soluble Phosphorus in runoff	0.26 lbs/acre
Soluble Phosphorus concentration in runoff	0.44 ppm
Total soluble chemical oxygen demand	61.73 lbs/acre
Soluble chemical oxygen demand concentration in runoff	104 ppm

Sediment Analysis

Particle type	Area Weighted Erosion Upland (t/a)	Area Weighted Erosion Channel (t/a)	Delivery Ratio (%)	Enrichment Ratio	Mean Concentration (ppm)	Area Weighted Yield (t/a)	Yield (tons)
CLAY	0.07	0.00	53	19	133.54	0.04	336.8
SILT	0.12	0.00	0	0	0.64	0.00	1.6
SAGG	0.74	0.00	0	0	0.72	0.00	1.8
LAGG	0.46	0.00	0	0	2.45	0.00	6.2
SAND	0.09	0.00	0	0	0.77	0.00	1.9
TOTAL	1.47	0.00	3	1	138.12	0.04	348.3

FIGURE 16

Sediment Associated Nutrient Loading West Boggs Lake Problem Cells in Meadow

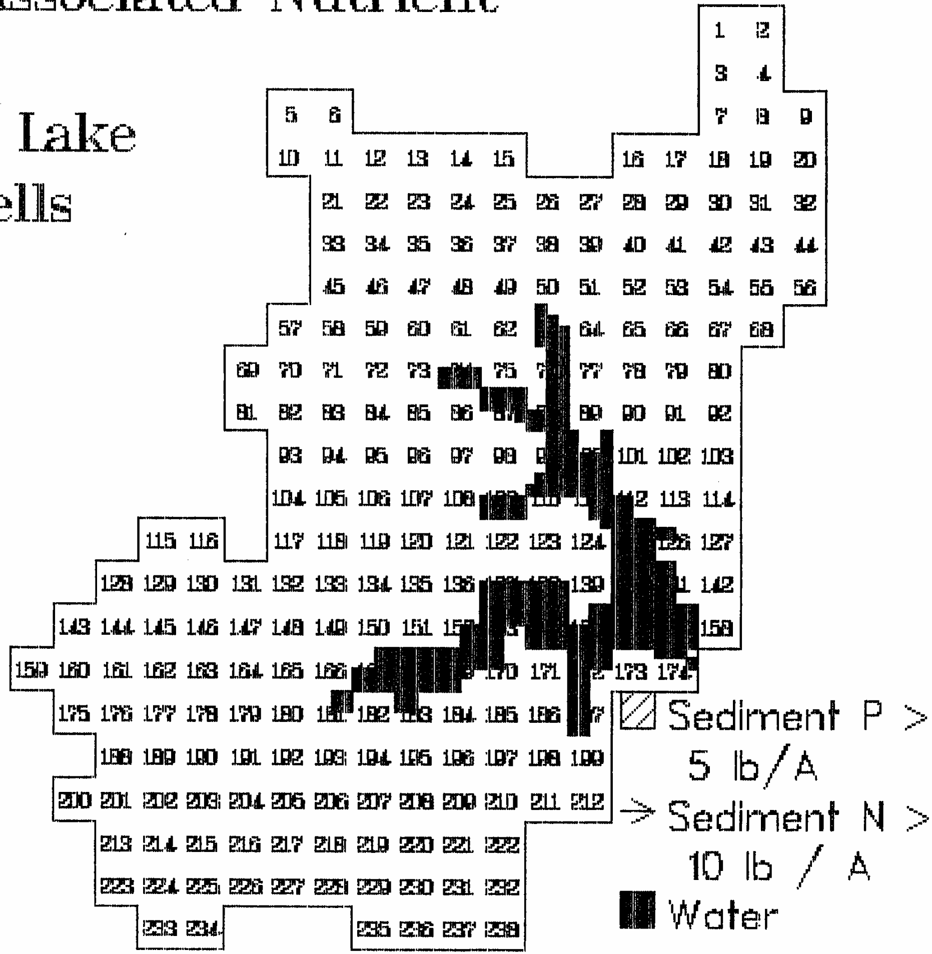
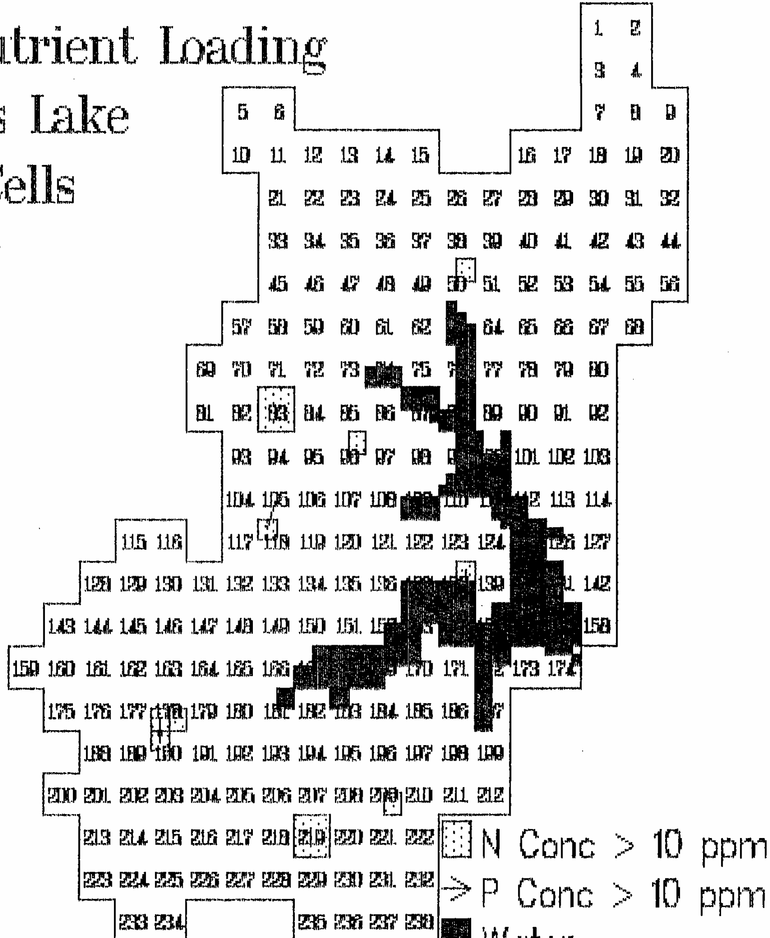


FIGURE 17

Soluble Nutrient Loading
West Boggs Lake
Problem Cells
in Meadow



Buffer areas between the feedlot and the point where the runoff becomes colonialized are also observed as to their existence, the travel distance before reaching the channel, slope of the buffer area and the surface condition constant. These parameters, as well as the animal species and stage of growth, and the number of animals, are all sources of data which influence the pollution potential of the feedlot.

In compiling feedlot data, it became evident that there are a large number of residents in the watershed who maintain small flocks or herds of domestic animals for use as draft animals, and to produce dairy, egg, and meat products for private consumption. Additionally, the vast majority of the farmers in the watershed are relatively small operators who rely on draft animals to some degree. The emphasis then was placed on farm operations which seemed to be the most likely sources of soluble nutrients reaching the lake. Data was assembled on twenty-four such lots by interviewing local livestock producers and observing the characteristics and stocking rates of the lots. Figure 18 17 depicts the location of the feedlots examined in this feasibility study. The twenty-four feedlots are located in twenty-three different 40 acre cells.

The feedlot rating system intrinsic to AGNPS is an involved analysis of COD/BOD ratios, the concentration in ppm and mass loading in lb./A/day of Nitrogen, Phosphorous, and COD and other factors. A thorough analysis of the ratings of the feedlots in the West Boggs Lake watershed is beyond the scope of this study. Therefore, the default values (upon which the

AGNPS program bases the rating) were used in designating the feedlots as being "high" or acceptable in terms of soluble phosphorus, soluble nitrogen, and COD. Figures 18 and 19 indicate that all cells having feedlot data input, were identified as having high phosphorus leaving the cell. All but six cells with reported feedlots have high levels of nitrogen leaving the cell as is depicted in Figure 20. Figure 21 shows nine of the twenty-three cells have high levels of COD associated with feedlots.

In observing the feedlots, it was noted in numerous instances a buffer of significant size was lacking between the lot and the nearest down gradient ditch or drain. In some cases, the ditch is included in the lot to serve as a water source for the livestock. While convenient to the producer, this practice provides an uninterrupted conduit for soluble nutrients and other contaminants to the lake. Treatment Four then involves restricting the domestic animals from access to the waterways by way of a buffer between the lot and the water conveyance. The buffer simulated in this treatment is a minimum of 300 feet of permanent meadow which has the natural filtering ability to remove soluble nutrients from sheet runoff. Three hundred feet was chosen as a minimum. This is a realistic size for the producer to maintain in most instances and is large enough to provide significant filtering action. The result of this simulated buffer is displayed in Figures 22, 23, and 24. Figure 22 indicates one less cell has a high level of Phosphorous leaving the cell. The level of soluble Nitrogen

FIGURE 18

West Boggs Lake
Rated Feedlots
Existing

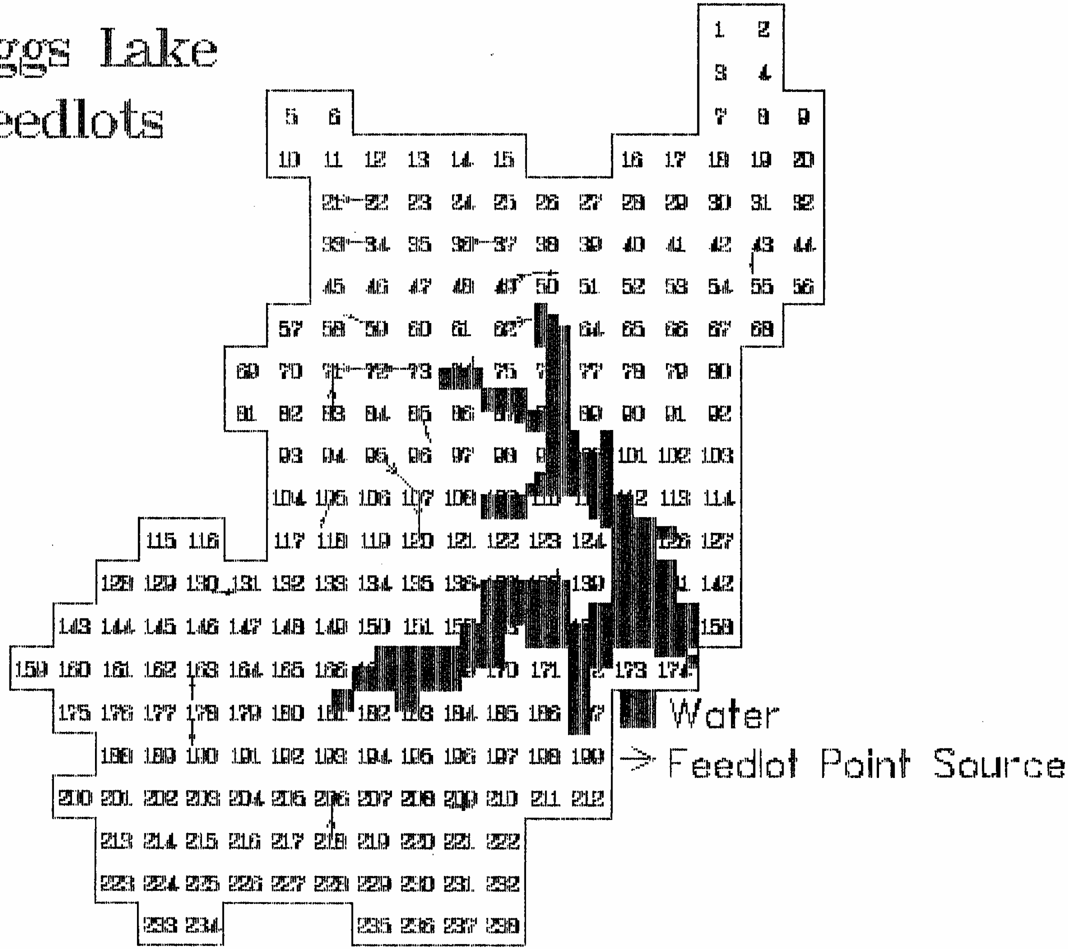


FIGURE 19

West Boggs Lake
Rated Feedlots
Existing

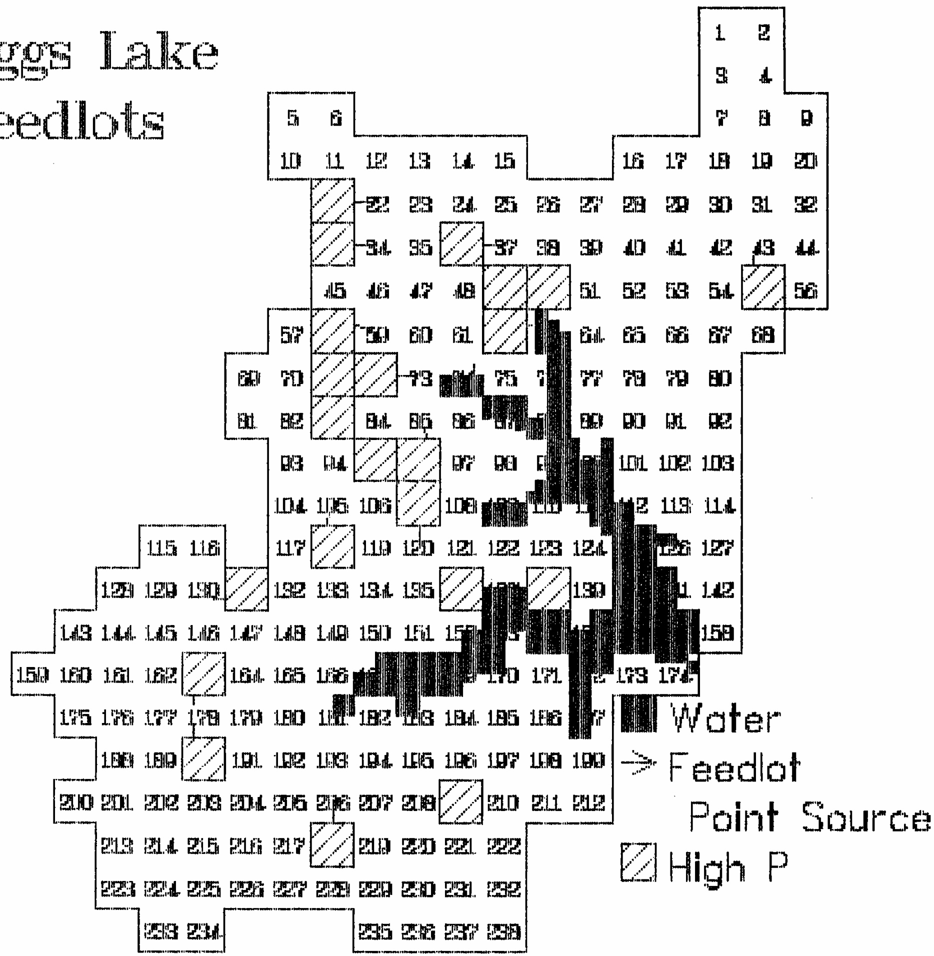


FIGURE 20

West Boggs Lake
Rated Feedlots
Existing

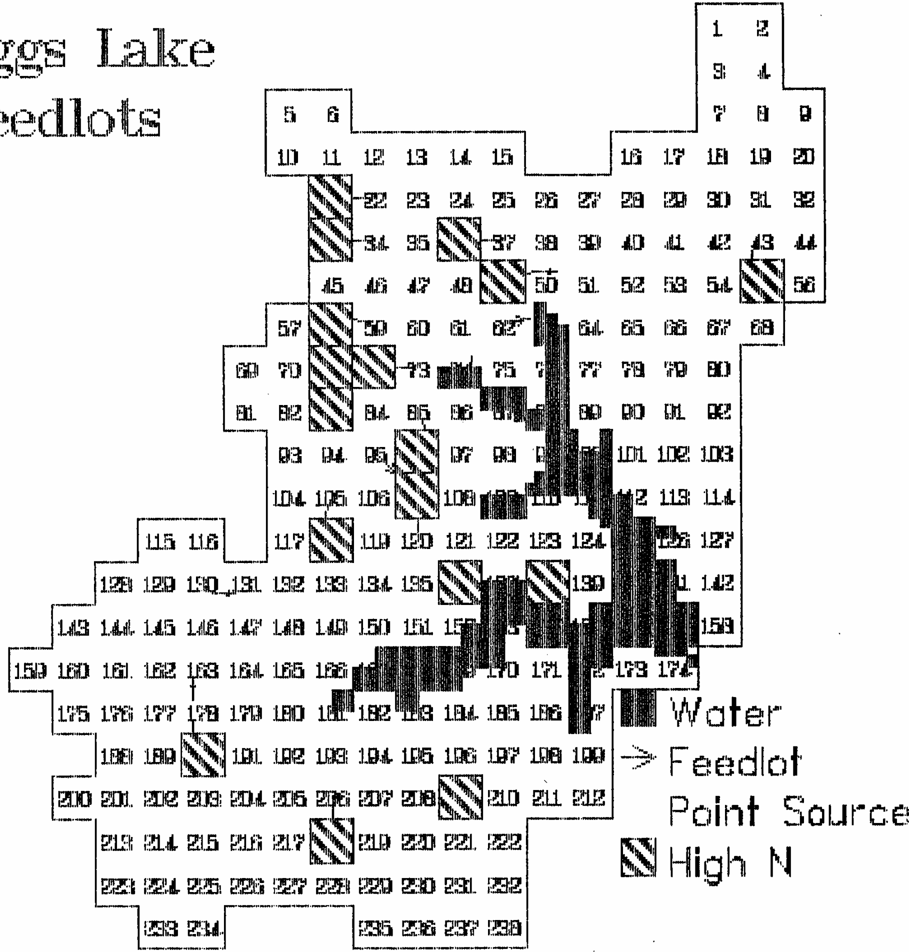


FIGURE 21

West Boggs Lake
Rated Feedlots
Existing

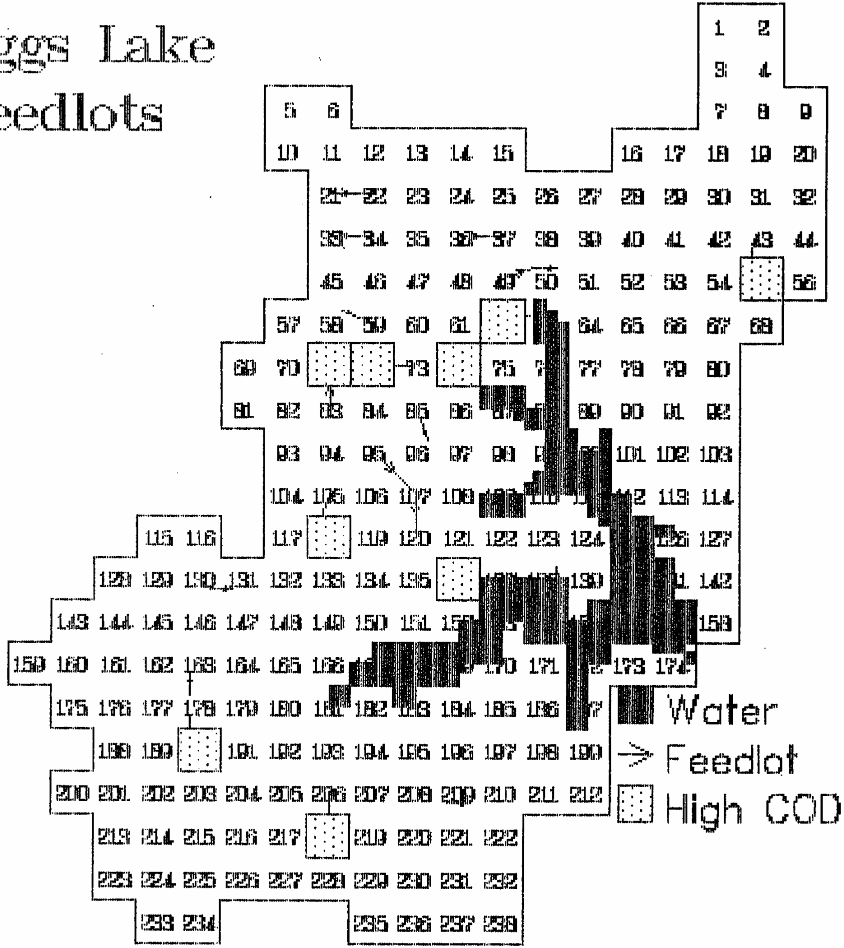


FIGURE 22

West Boggs Lake
Rated Feedlots
Minimum 300 ft
Meadow Buffer

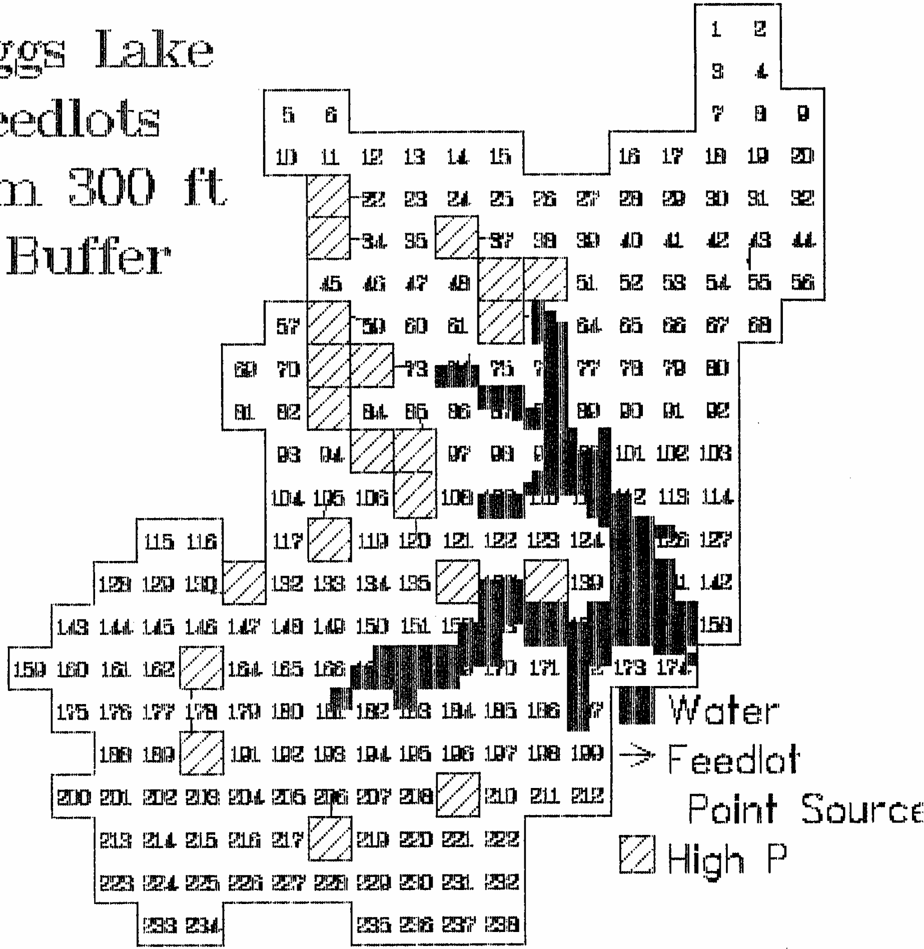


FIGURE 23

West Boggs Lake
Rated Feedlots
Minimum 300 ft
Meadow Buffer

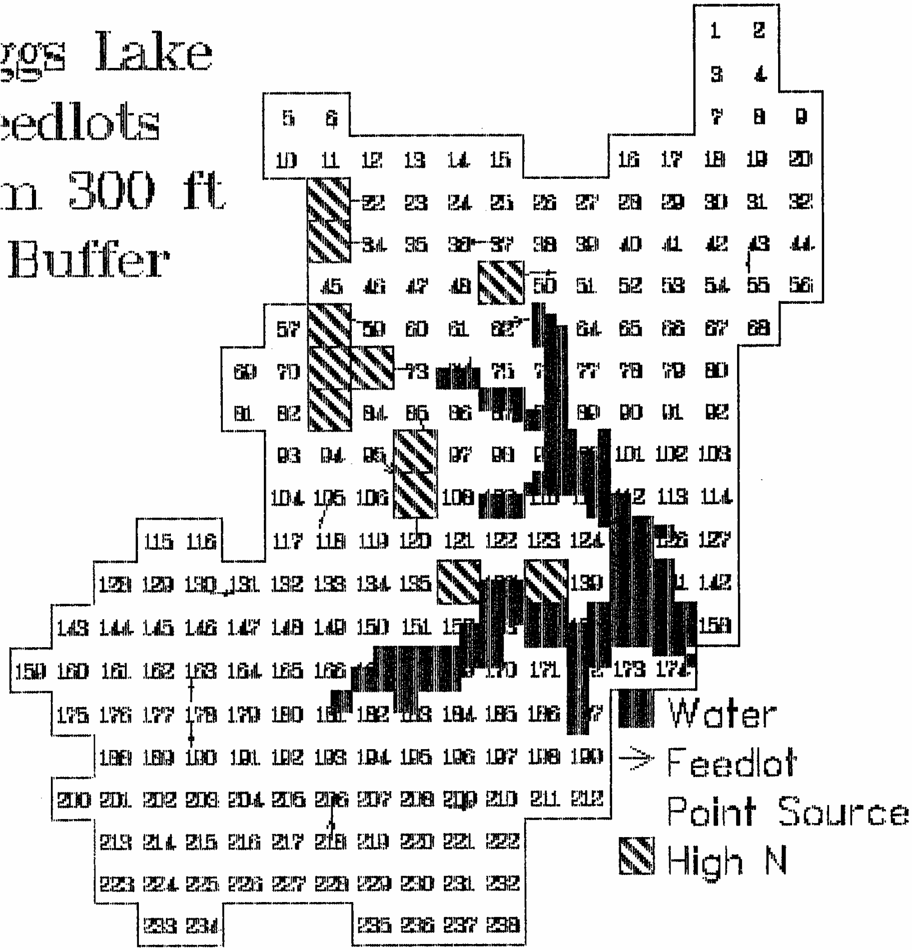
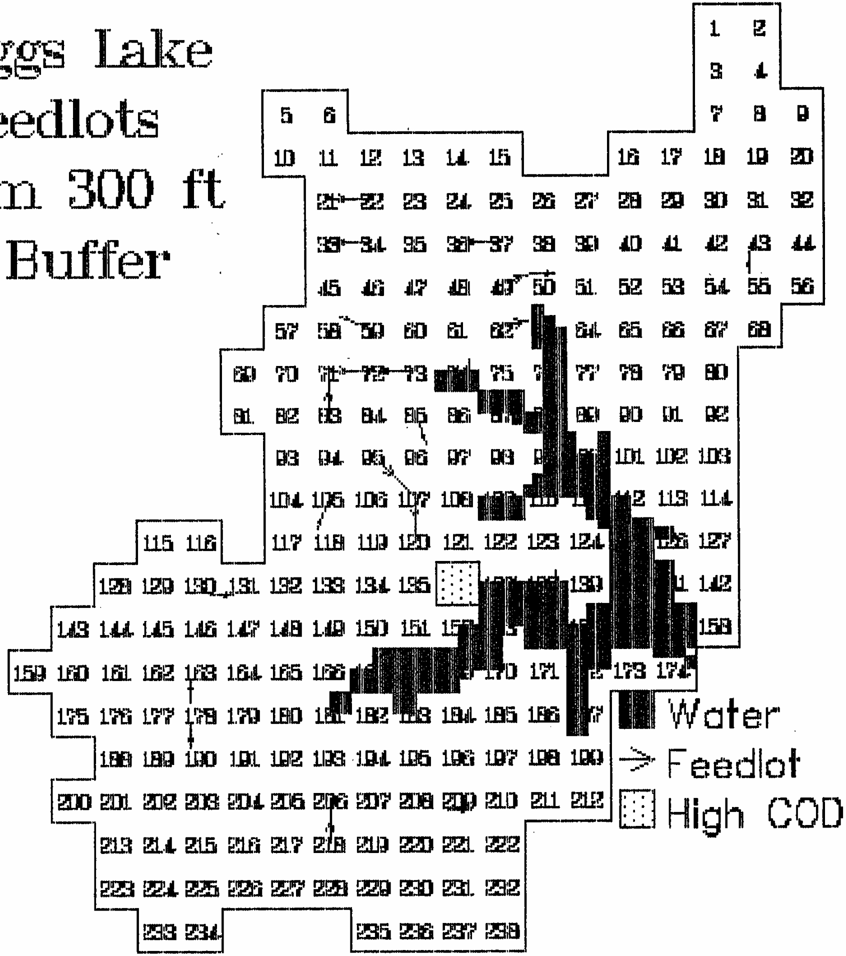


FIGURE 24

West Boggs Lake
Rated Feedlots
Minimum 300 ft
Meadow Buffer



has dropped to acceptable limits in six cells as a result of the buffer as is evidenced in Figure 23. Figure 24 reflects the reduction of COD generated by the feedlot cells with only one cell remaining to have a high COD output. Actual reductions in nutrient and COD loading was not measured on a per cell basis, however the watershed summary (Table 15) shows a reduction in concentration of 0.18 ppm for nitrogen, 0.04 ppm for phosphorus, and 3 ppm for COD. Mass loading of soluble nitrogen has been reduced 0.11 lb./A. Soluble Phosphorous has dropped by 0.03 lb./A and COD has declined 1.64 lb./A. These reductions may appear insignificant until the units are considered. A reduction of 0.11 lb./A x 8530 acres yields 938.3 lb. of soluble nitrogen that <u>does not</u> enter the lake during the design storm.

4.4 Treatment Summary

The treatments simulated have been presented as attempts to key in on definitive problems with specific actions to resolve the problems. The treatments involve using No-till methods in the second year corn crop of a five year crop rotation in cells with problem soil losses. The cells that continue to have excessive erosion would require No-till methods for both corn crops in the second treatment. Those crops that continue to lose excessive soil would be taken out of production and established as permanent meadow in the third treatment. Treatment Four is an attempt to maintain a minimum size buffer between feedlots and channels which transport the runoff to the lake. The first three treatments ideally build on each other

TABLE 15

BEFORE BUFFER STRIPS

Watershed Summary

Watershed Studied	WEST BOGGS LAKE
The area of the watershed is	8530 acres
The area of each cell is	40.00 acres
The characteristic storm precipitation is	4.50 inches
The storm energy-intensity value is	125

Values at the Watershed Outlet

Cell number	174 240
Runoff volume	2.7 inches
Peak runoff rate	3829 cfs
Total Nitrogen in sediment	0.85 lbs/acre
Total soluble Nitrogen in runoff	1.59 lbs/acre
Soluble Nitrogen concentration in runoff	2.63 ppm
Total Phosphorus in sediment	0.42 lbs/acre
Total soluble Phosphorus in runoff	0.28 lbs/acre
Soluble Phosphorus concentration in runoff	0.46 ppm
Total soluble chemical oxygen demand	65.63 lbs/acre
Soluble chemical oxygen demand concentration in runoff	109 ppm

AFTER BUFFER STRIPS

Watershed Summary

Watershed Studied	WEST BOGGS LAKE
The area of the watershed is	8530 acres
The area of each cell is	40.00 acres
The characteristic storm precipitation is	4.50 inches
The storm energy-intensity value is	125

Values at the Watershed Outlet

Cell number	174 240
Runoff volume	2.7 inches
Peak runoff rate	3829 cfs
Total Nitrogen in sediment	0.85 lbs/acre
Total soluble Nitrogen in runoff	1.48 lbs/acre
Soluble Nitrogen concentration in runoff	2.45 ppm
Total Phosphorus in sediment	0.42 lbs/acre
Total soluble Phosphorus in runoff	0.25 lbs/acre
Soluble Phosphorus concentration in runoff	0.42 ppm
Total soluble chemical oxygen demand	63.99 lbs/acre
Soluble chemical oxygen demand concentration in runoff	106 ppm

but may be implemented in varying degrees. Any measures to reduce the raw runoff from feedlots is also regarded as a positive step.

4.5 AGNPS Limitations

In conclusion, the treatments proposed and modelled by AGNPS are not intended to correct all nutrient and soil loading problems in all cells. There are numerous other watershed management techniques that could be selected for modeling. Donan Engineering chose to model the above listed treatments based on their effectiveness and ease of implementation given the present practices of the watershed land owners. The treatments are designed also to be effective, even if only partially implemented. An important note is that the AGNPS model is a theoretical modeling of a particular storm event, and these recommendations are ideal, hypothetical solutions. Septic systems often have significant nutrient contributions as well. However, AGNPS is not designed to implement septic tank data.

5.1 Introduction

G. Evelyn Hutchinson has established himself as an expert in the field of limnology. While serving as professor in the Department of Zoology at Yale University, he authored a multiple volume work entitled A Treatise on Limnology which is recognized internationally as one of the greatest limnological works. Mr. Hutchinson quotes "Lakes seem, on the scale of years or of human life spans, permanent features of the landscape, but they are geologically transitory...to mature and die quietly and imperceptibly." (Hutchinson, 1957). The concept of which Mr. Hutchinson was referring to is known as eutrophication. Eutrophication is the aging process of a lake. All lakes and reservoirs undergo eutrophication. As described earlier, eutrophication, by definition is "... the process of excessive addition of inorganic nutrients, organic matter, and/or silt to lakes and reservoirs, leading to increased biological production and a decrease in volume" (Cooke, 1986).

As a contrast, lakes and reservoirs exposed to the effects of human culture can, in fact, change very rapidly and conspicuously. This is known as cultural eutrophication. Lakes and reservoirs undergoing cultural eutrophication will lose much of their beauty, their attractiveness for recreation, and their usefulness as industrial and domestic water supplies. Rooted and floating plant masses may become so dense

SCS
Lake Waveland
West Boggs Lake
Lake Sullivan
Prides Creek Lake
Montgomery Lake
Bischoff Res.

High watershed to lake area ratios.
watershed - ~~[illegible]~~ highly agricultural & erosive soils

The Work Plan for West Boggs - 0.66 in or 468 ac-ft of sediment was predicted for the lake in 50 years. My mind - ridiculously low.

that many uses of the water are curtailed. Symptoms such as algal blooms, rapid loss of volume in reservoirs, noxious odors, tainted fish flesh and domestic water supplies, dissolved oxygen depletion, fish kills, and the development of nuisance animal populations (e.g. common carp or gizzard shad) can bring about economic losses in the forms of decreased property values, depressed recreation industries, expenditures for herbicide applications, and the need to build new reservoirs (Cooke, 1986). West Boggs Lake is suffering from cultural eutrophication. It is already experiencing several of these symptoms and will continue to experience all of these symptoms in time if no treatment is exercised.

The following treatments will focus on curtailing the cultural eutrophication that West Boggs is currently experiencing. Three different categories of treatments will be discussed. The first is current management techniques, the second is watershed management techniques, and the third is in-lake management techniques.

5.2 <u>Current Management</u>

At the present time, there is no written management plan for West Boggs Lake. In the past, there has been little if any effort to address watershed management issues as well. One of the goals of this study is to produce an agenda of items that should be addressed in a written management plan. A written plan should outline long term goals for managing the lake and its watershed as well as procedures for obtaining those goals.

Continuing without a written management plan would not be an adequate response to the critical problems facing West Boggs Lake at this time, nor would it adequately insure future lake quality. Under current conditions, all facets of cultural eutrophication, as previously described, could eventually prevail. *could or would ?*

5.3 Watershed Management Techniques

Watershed management is an extremely important lake restoration concept. A common principle accepted among lake managers and limnologists is that a lake is a reflection of its watershed. Watershed management techniques are the only ways to correct the causes of water quality problems and not just focus on treating the symptoms. There are three existing conditions that can be addressed in West Boggs Lake's watershed. The first is the high representation of highly erodible soils in the watershed combined with the cropping practices presently used. Second is the management of the feedlots throughout the watershed. Third is the absence of sewer lines to serve the lake shore residences. A combination of these factors are promoting the eutrophication process at West Boggs Lake.

5.3-1 Highly Erodible Soils and Cropping Practices

Approximately 72% of the soils in the watershed are classified as highly erodible (See the "Distribution of Highly Erodible Soils" map included in the Appendix). This classification results from the natural soil characteristics and is independent of land uses; consequently, nothing can be done to change this classification. However, better management of the soils can change the susceptibility of the soils to erosion processes. The watershed management recommendations detailed in the AGNPS section of this report provide effective initial guidelines for curtailing excessive sediment and nutrient loading to the lake. Briefly summarizing, these treatments involve using No-till methods in the second year corn crop of a five year crop rotation in cells with problem soil losses. The cells that continue to have excessive erosion would require No-till methods for the two corn crops in the second treatment. Those crops that still lose excessive soil would be taken out of production and established as permanent meadow as a third treatment option. These first three treatments ideally build on each other but may be implemented in varying degrees. Any management decisions motivated by the desire to provide better stewardship of our soil and water resources is to be encouraged. Whether it be conservation tillage or radical changes in landuses, better management practices will ultimately have a positive effect by reducing soil losses to the lake.

There are several other watershed management techniques not modeled by AGNPS which could be very effective in controlling nutrient and sediment runoff as well. Some of these options would include other conservation tillage practices, improved soil fertility, plow-plant systems, contouring, contour strip cropping, dry dams (WASCOBS), other drop structures, terraces, grassed outlets, contour furrows, diversions, or subsurface drainage. The farmers in the watershed should be encouraged to coordinate efforts with their local Soil Conservation Service (either Daviess or Martin Counties) to determine which of these practices or activities would be appropriate.

5.3-2 Feedlot Management

According to the AGNPS computer model, feedlots are responsible for contributing high levels of soluble nutrients to the lake. The field study conducted by Donan Engineering documented that many feedlot operations either had channels flowing through or near the feedlot area. When a channel bisects a feedlot, it is a worst case scenario for contaminating the water. When a channel bisects a feedlot area, it should be diverted or the feedlot should be adjusted to avoid contamination problems. Treatment Four of the AGNPS computer model illustrated that maintaining a minimum size vegetation buffer strip of 300 feet between feedlots and channels which transport the runoff to the lake will significantly reduce the amount of soluble nitrogen, phosphorus and COD reaching the lake. Therefore, feedlot operation owners should be strongly advised to establish buffer strips between their feedlot and the nearest channel.

The State of Indiana recently enacted a classified filter strip law (H.B. 1604). Under this program filter strips may be classified for property tax purposes and assessed at a value of one dollar per acre. The Soil and Water Conservation District should be able to provide assistance in this matter.

5.3-3 Management of Human Sewage

The residences surrounding West Boggs Lake are presently not serviced by a sewer system as was discussed in Section 3.8. According to the State Board of Health, the only approved ways to dispose of sewage, aside from sewers, is the proper installation of a sanitary vault privy or the proper installation of a non-failing septic tank with a soil absorption system. Temporary sewage holding tanks or any other system, without approved written consent from the Commissioner, are no longer allowed to be used by law and should be replaced with an acceptable system.

There are no sewer lines extended to service the residents along the lakeshore of West Boggs; therefore, it is highly probable that there are several sewage systems that no longer conform to the proper standards. No records could be located indicating that a sewage disposal method survey of the residents along the lake shoreline has been conducted. It is recommended that the Daviess and Martin County Sanitarians and the West Boggs Park personnel verify the sewage disposal methods that are currently being used by these residents and insist on the updating of the systems to proper standards as defined by 410 IAC 6-8.1.

5.4 In-Lake Management Techniques

5.4-1 In-Lake Nutrient Control

Watershed management techniques are a first priority for limiting nutrient inputs. No in-lake restoration method is available that will yield long term solutions to improve water quality if watershed management techniques are ignored. However, even after external inputs of nutrients have been reduced it may be found that water quality is not improving as expediently as needed. This often is the case since nutrients and contaminants increase in the sediments over time. These nutrients are cycled throughout the lake during different times of the year and will continue to promote excessive algal and macrophytic growth. When this occurs, internal recycling of nutrients needs to be controlled by implementing some form of in-lake treatment. This can be controlled through several in-lake methods such as (1) Phosphorus precipitation and inactivation through application of sodium aluminate (2) sediment oxidation (3) sediment removal or dredging or (4) hypolimnetic aeration or withdrawal. However, the recommendation of any of these in-lake treatment methods is premature. Watershed management techniques need to be implemented first; after which, a reassessment of the water quality should be made to determine if any in-lake treatment methods should be employed.

5.4-2 Influent Nutrient and Sediment Control

Wetlands and sedimentation basins are a separate type of restoration. After watershed management practices have been implemented, wetlands will often provide a very effective final filtration system before the water enters the lake. Properly designed and properly maintained wetlands can have many positive impacts on water quality. Wetlands are often referred to as "the kidneys of the landscape" for the functions they perform in hydrologic and chemical cycles. Wetlands have been found to cleanse polluted waters, prevent floods, protect shorelines, and recharge groundwater aquifers. Furthermore, wetlands play major roles in the landscape by providing unique habitats for a wide variety of flora and fauna (Mitsch & Gosselink, 1986). Wetlands are not considered a watershed management tool, but rather an in-lake treatment process. Therefore, wetlands alone would only address the symptoms and be deficient to correct the cause of the water quality problems. Wetlands could be developed on several legs of the lake to provide natural nutrient and sediment filters as well as a healthy fishery habitat.

Sedimentation basins can often be constructed in conjunction with a wetland area. These basins provide a mechanism to collect the sediment before it enters the wetland. This will extend the life expectancy and the efficiency of the wetland.

The area located west of St. Mary's Road just south of County Road 600 North has been functioning as a natural sedimentation basin for several years. A natural wetland has developed in this area and should be taken advantage of by preserving it. The Park Board may even choose to highlight this embayment as a wildlife area for the enjoyment of naturalists that visit the park. A structural sediment basin could then be constructed upstream from this area to retain incoming sediment, while the wetland could serve as a nutrient filter before the runoff enters the lake. A design study would need to be conducted to determine the specification requirements for a basin to be effective.

Another area of major concern is the west end of the Shurn Creek leg. It is estimated that several acres have already been lost due to excessive soil loading from subwatershed N. The sediment loading to this leg will certainly increase over time if no action is taken to curtail it. A sediment basin or basins can be constructed upstream from this area to retain suspended sediment before it reaches this area. A design study would need to be conducted to determine the specifications of a basin needed to be effective as well.

There are several costs involved with constructing sediment basins. Design costs will be approximately $300-$500 per basin designed. Construction of the basins will be approximately $1.50 per cubic yard of basin volume constructed. The cost of dredging would range from $2.00 to $5.00 per cubic yard. Disposal costs of the dredged soil would be variable due to hauling distance, storage time, and potential value as fill and/or topsoil material. A permit from the U.S. Corps of Engineers may be necessary based on how the dredged material is stored, where it is placed, and other factors.

5.4-3 Shoreline Stabilization

A large portion of the shoreline surrounding West Boggs Lake is experiencing erosion problems. Many lake shore residents have voiced verbal concern regarding the loss of the shoreline next to their homes and surrounding their boat docks. This erosion is also supported by the photographic documentation presented within this report.

The interesting scenario at West Boggs Lake is that West Boggs Park actually owns all of the shoreline surrounding the lake. More specifically the Park property extends approximately one hundred feet from the shore which is intended to include the lake's floodplain. This puts the responsibility to implement shoreline stability programs on West Boggs Park. However, many lake shore residents have stated that they are willing to assist the Park in implementing shoreline stability programs. The Park Board is strongly encouraged to take advantage of the ownership of the shoreline by implementing mechanisms that will reduce the shoreline erosion.

There are several different ways to curtail shoreline erosion involving both structural and non-structural control options. Structural options include gabions, rip-rap, and seawalls. Non-structural options includes establishing vegetation or implementing beach sloping. Curtailing lake wave action is often a mandatory management option for controlling shoreline erosion. Choosing the correct shoreline erosion control method(s) should be considered on a case-by-case basis established upon the physical characteristics of the particular area.

5.4-3A <u>Non-Structural Controls</u>

Non-structural controls refer to establishing vegetation or beach sloping. Both of these types of non-structural controls are discussed below.

Vegetation

Vegetation can effectively control runoff erosion on slopes or banks leading down to the water line which originate from the watershed. However, some authors have noted that vegetation is sometimes ineffective against direct wave action or seepage-caused bank slumping. Donan Engineering is of the opinion that a majority of the shoreline erosion is due to wave action. Therefore, the establishment of vegetation will be ineffective as a control measure in itself for addressing wave action erosion. However, combined with other wave action curtailing programs, the establishment of vegetation may be effective for stabilizing various areas.

For erosion control, plants can be grouped into three categories: herbaceous plants (includes grasses and ground cover), shrubs, and trees. The type of vegetation to establish depends inpart on the steepness of the slope. If the slope is steeper than 1:1, the soil is probably unstable and the possibility of establishing vegetative cover with success is minimal. If possible, the bank should be reshaped to a flatter slope. On slopes flatter than 3:1, a mowed lawn is feasible. On slopes between 1:1 and 3:1, a mowed lawn is difficult to maintain and other options recommended include unmowed grasses, shrubs, or trees (McComas etal, 1986).

The following classifications and recommendations were adopted from an article published by Mr. Steve McComas etal. Mr. McComas etal published an article in Lake and Reservoir Management: Volume II in 1986 entitled "Shoreline Protection" which can be referenced in the Appendix.

Grass mixtures for slopes flatter than 3:1
Tall fescue and common Kentucky bluegrass mixture is appropriate for a mowed lawn and can be established in one year.

Grass mixtures for slopes flatter than 1:1
Red fescue and common Kentucky bluegrass mixture reaches a mature height of 12 - 18 inches and can be established in one year. Big bluestem, little bluestem, and switchgrass, reaching a mature height of 36-60 inches, are native prairie grasses and may take several years to become established.

Ground cover plants for slopes flatter than 1:1
These plants can be used instead of grass on slopes. They often are more attractive than unmowed grass and usually require less maintenance. They take one to several years to become established. Representatives include goutweed, bearberry, crown vetch, memorial rose, bugleweed, creeping juniper, and purple wintercreeper.

Shrubs for slopes flatter than 1:1
Shrubs are woody plants best transplanted in spring when they are dormant. Plant after the ground thaws and the air temperature is above 35 degrees F. Planting can also be done in late autumn after the plants are dormant but before the ground freezes. They take one to two years to become established. Representatives include red chokeberry, gray dogwoods as well as other species of dogwoods, sumac, common juniper, common witch hazel, border privet, snowberry, and tatarian honeysuckle. Willow plantings???

Erosion Control Mats
Erosion control mats serve as a reinforcing matrix for root systems. The mats, constructed of a nylon mesh or wood excelsior, are placed on top of soil to assist in seed germination, seeding protection, and erosion control. They control erosion on slopes carrying water with a velocity that makes it difficult for unaided vegetation to grow effectively. Different types of mats are recommended for different flow velocities. Erosion control mats can be used in channels, in ditches, and on slopes, but are not designed to dissipate energy of direct wave action. In summary, vegetation alone or combined with erosion control blankets controls erosion originating from the land side of the lake.

Prices for various types of vegetation will vary depending on the species and whether tubers or seed are planted. For

Elev. (Normal Pool) - 499.6
Elev. (E.S.) - 503.6

Say, 2 ft. drawdown for a dry year -
Elev. 497.6

$$\begin{array}{r} 503.6 \\ \underline{497.6} \\ 6.0 \end{array}$$ ft. minimum for wave protection

example, the following are current costs for 1,000 tubers, which will plant one acre at the recommended planting density: Sago pondweed ($130), wild celery ($140), and hardstem bulrush ($160). Enough reed canary grass seed to plant one acre costs $46.80 (at 12 lbs. per acre) (Jones, 1991). Various nurseries will also often provide price lists of specific vegetation chosen.

The "Shoreline Erosion" article discusses prices associated with various types and brands of Erosion Control mats or blankets. The type or brand of erosion control blanket that will be needed to adequately stabilize the shoreline will be dependent upon the type of soils present and the expected linear velocities of the waters. Even though the article was written in 1986, the listed prices still give some idea of what this alternative will cost. The listed range is from $0.51 to $6.70 per square yard.

The elevation difference between the emergency crest and that for 2-3 ft. drawdown from the normal pool level during dry periods is a real problem.

Beach Sloping (McComas etal, 1986)

The concept of beach sloping is to create beaches to take advantage of the ability of semifluid sands to dissipate the energy of the breaking and receding waves. Design considerations include:

1. Minimum thickness of the sand blanket is one foot.

2. Extend the blanket to a water depth two times the design wave height. If the design wave height is one foot, then the sand blanket should go into the water to a depth of at least two feet. If the final beach slope is 10:1, then the blanket goes into the lake 20 feet from shore (water depth will be two feet at 20 feet from shore at slope of 10:1).

3. Extend the beach blanket the distance equal to the computed runup plus one foot.

4. The material used and the final slope should be determined by a professional engineer.

5. One problem with beach sloping is that a strong long-shore current may erode blanket material. Periodic replenishment will be necessary in this case.

An example of a cross section of beach sloping can be referenced in the "Shoreline Protection" article in the Appendix.

The price associated with beach sloping basically consists of sand and gravel. Sand was priced at about $6.89 per ton on the average, gravel was priced at about $4.09 per ton on the average. Based on a hypothetical design of having beach sloping extend thirty linear feet (twenty (20) feet into the water and ten (10) feet onto the shore) with three (3) inches of gravel and one (1) foot of sand, it will cost approximately $15 per linear foot of shoreline plus labor and hauling costs.

5.4-3B Structural Controls

Rip-Rap is a flexible structure that consists of stacking rocks along an eroding bank. This can be effective if done correctly. As documented earlier in this report, rip-rap already exists in several different locations along the lakeshore with marginal success. Factors influencing the success of rip-rap are the depth that the rip-rap extends into the water, the height of the rip-rap on the shore, the size of rocks used, the thickness of the rip-rap, the slope of the shore, and the layering of the rip-rap. The layering will often consist of a graded stone filter or filter fabric, small stones placed on the blanket with larger stones, often referred to as armor, on top of the smaller stones. If all these parameters are addressed, the rip-rap will be much more successful in controlling erosion. Specific requirements of rip-rap can be referenced in the "Shoreline Protection" article in the Appendix.

Costs associated with rip-rap will vary. Most companies price rip-rap by the ton. This price usually will include associated grading, and placement of the filter fabric, bedding stone, and armor. Some general prices for this type of service will usually range anywhere between $40 - $80 per ton. One ton of rip-rap will cover an area of approximately 5 feet long (from beneath the surface of the water to the top of the rip-rap) by 3 feet wide (across the shoreline) by 1 foot thick or about 15 cubic feet.

Gabions are large bales of rocks. A non-rusting, non-deteriorating mesh material is used to form a cubic structure which is filled with rocks. These can be easily stacked to form a rigid control structure, and are very effective in controlling erosion. However, they are most commonly used along stream banks and their applicability for stabilizing lake shorelines is limited.

Seawalls are by far the most effective method to control shoreline erosion. A seawall eliminates the shoreline altogether by establishing a permanent buffer between the water and the soils. Seawalls can be constructed of treated lumber or aluminum. Concrete seawalls are not recommended for areas such as the midwest where lakes freeze during the winter.

Seawalls will vary in price. One of the major factors is how high the wall needs to extend above the water level. This price usually will include the materials and the labor to install the seawall. Some general prices for treated lumber seawalls range from approximately $120 per linear foot of shoreline for 5 feet exposed height to approximately $250 per linear foot of shoreline for 8 feet exposed height. Some general prices for an aluminum seawall is approximately $150 - $200 per linear foot of shoreline.

Structural erosion control options have minimal positive attributes or effects for fisheries management or any other aquatic organisms; however, these are often the only real option for controlling severe shoreline erosion from wave action. One factor to consider in installing some structural controls is that the lake may need to be drawn down in order to conduct installations. These types of control options can also have less aesthetic values for lakeshore residents. Additional specifications on structural control methods can be referenced in the "Shoreline Protection" article included in the Appendix.

5.4-3C Curtailing Wave Action

All of the above mentioned erosion control mechanisms are important in protecting the shoreline; however, implementing these erosion control measures only addresses the symptoms and does not address the causes. The primary action that should be taken at West Boggs Lake is to implement and enforce actions that will curtail the wave action.

The first part of this action could include establishing emergent vegetation along certain areas of the lakeshore. This emergent vegetation will dissipate the energy of the waves and consequently be a first step in protecting the shoreline. During our aquatic vegetation survey at West Boggs, it was determined that the lake could use more aquatic vegetation. Establishing specific types of vegetation in specific areas will not only dampen the wave action, but also provide a healthy habitat for fish cover and spawning, provide an additional source of food for certain animals, and improve the overall ecosystem balance. The establishment of emergent vegetation may have marginal success at West Boggs Lake due to the Carp population according to Mr. Steve Andrews, District Fisheries Biologist. Therefore, the Park Board may want to implement some trial plantings before developing a full-scale planting project.

Some rooted, emergent plants known to grow in midwestern lakes include the following (Engel:

Emergent species: plant rootstock in ankle-deep water.

Common Name	Scientific Name
Common arrowhead	Sagittaria latifolia
Pickerelweed	Pontederia cordata
Slender spikerush	Eleocharis acicularis
Sweetflag	Acornia calamus
Reed canary grass	Phalaris arundinacea

Emergent species: plant rootstock or seed no greater than waist deep.

Common Name	Scientific Name
Hardstem bulrush	Scirpus acutus
Common cattail	Typha latifolia
Sedge	Carex spp.
Wild rice (seeds only)	Zizania aquatica

Selection of potential areas and emergent species establishment should be coordinated with the IDNR Division of Fish and Wildlife.

The primary response in curtailing wave action is to limit the speed and access of boats. According to the Indiana Boating Laws, published by the Law Enforcement Division of the Indiana Department of Natural Resources, 14-1-1-29 states "No person shall operate any motorboat so as to approach or pass within two hundred (200) feet of the shore line of any lake or channel thereof at a rate of speed greater than ten (10) miles per hour...". The map entitled "Boating Zones: Speed Restrictions" is included in the Appendix. The map reflects that the entire area west of St. Mary's Road is currently an idle zone. This map also delineates an area 200 feet from the shoreline. This is the only area where boats can exceed 10 miles per hour by Indiana State Law. Donan Engineering recommends that the lake be divided into different speed zones. All boats that are within 200 feet of the shoreline should not exceed 10 mph by State law. These are the white areas on the map. The next zone is the reduced speed zone. In this zone, it is recommended that boats not exceed 15 mph. The remaining zone will be an unlimited speed zone which will also serve as a water skiing zone. If West Boggs Park decides to adopt this recommendation, a major reduction in wave action will occur. This should be the primary step to curtailing shoreline erosion at West Boggs. It is imperative that if adopted, the speed zones be clearly buoyed and labeled as well as strictly enforced. Even if the recommended zones are not adopted, strict enforcement of the delineated 200 foot barrier and the current idle zone west of St. Mary's road is necessary.

Section 6. CONCLUSIONS AND RECOMMENDATIONS

In conclusion, there are numerous factors influencing the lake water quality at West Boggs Lake. The preferred management alternative consists of five responses which will address these numerous factors as well as address cost-effectiveness and recreational lake usage.

The first primary response is to implement watershed management activities. West Boggs Lake has been highly impacted over the past several years in regards to nutrient and sediment inputs from various sources in the watershed such as conventionally tilled farmland and feedlot operations. Due to this history, the lake is more susceptible and fragile with respect to nutrient and sediment loads. The AGNPS model demonstrated that certain land use changes can be implemented as part of the overall solution to reduce the impact of watershed activities. This generally included changing tillage practices of select cells and converting certain problem cells to permanent meadows, forests or wildlife refuges as well as adding or increasing the size of buffer strips around certain feedlot operations.

There are several other watershed management techniques not modeled by AGNPS which could be very effective in controlling nutrient and sediment runoff as well. Some of these options would include other conservation tillage practices, improved soil fertility, plow-plant systems, contouring, contour strip cropping, dry dams (WASCOBS), other drop structures, terraces, grassed outlets, contour furrows, diversions, or subsurface drainage. The farmers in the watershed should be encouraged to coordinate efforts with the local Soil Conservation Service to determine which of these practices or activities would be appropriate.

The reality of these events actually occurring without any participation of the Daviess and Martin County Soil Conservation Service offices and the West Boggs Park Board are highly unlikely. Promoting and enforcing watershed management practices should be the primary response to a preferred treatment alternative for West Boggs Lake. The Lake Enhancement Program is currently active in developing a Lake Watershed Land Treatment Program. The program is designed to provide cost-sharing and incentive payments to landusers in the watershed of a Lake Enhancement project lake for implementing land treatment practices that reduce sediment and nutrient inflows to the lake from agricultural sources. The Lake Watershed Land Treatment Program may be a potential source of funding for watershed treatment at West Boggs Lake. Additional information can be obtained about the Lake Watershed Land Treatment Program from the Indiana Department of Natural Resources, Division of Soil Conservation.

The second primary response is to address the sewage disposal practices from residences throughout the watershed, particularly along the shoreline. With the passage of 410 IAC 6-8.1, County Sanitarians have the authority to mandate that all sewage disposal systems throughout the watershed be inspected and modified to acceptable standards as defined by the Indiana State Board of Health. The West Boggs Park Board can encourage and assist the County Sanitarians to assure that the sewage systems are brought into compliance.

The third primary response is to address the shoreline erosion presently occurring around the lake. West Boggs Park has control of the entire shoreline around the lake. The Park should definitely take advantage of this situation and curtail the shoreline erosion as responsively as possible. While the shoreline is severely eroded in various areas, the Park Board could begin their efforts on controlling the erosion that is occurring around the Park itself. The eroding shoreline around the Park area may be perceived by the public as a negative or "strong statement" True??? "not caring" attitude by the Park. Shoreline erosion control around West Boggs Lake can be accomplished through implementing and enforcing actions that will curtail wave action on the lake. This could include introducing select types of emergent vegetation along certain areas of the lakeshore as well as implementing new boating speed zones which have been developed and proposed. Diminishing the occurrence of wave action in certain areas is the primary action that can be taken to diminish the shoreline erosion. In addition, either structural (rip-rap or seawalls), or non-structural (vegetation or beach sloping) shoreline erosion control options can be used to stabilize the shoreline. Selection of emergent species for establishment should be coordinated with the IDNR Division of Fish and Wildlife.

Prices for various types of vegetation will vary depending on the species and whether tubers or seed are planted. A range of prices to plant one acre of various plants at recommended densities was between about $50 to $160. The price associated with erosion control mats can approximately range between $0.50 to $7.00 per square yard. The price associated with beach sloping will depend on the design. A hypothetical design was evaluated and found to cost approximately $15 per linear foot of shoreline plus labor and hauling costs. Costs associated with rip-rap will vary as well. Some general prices for this type of protection will usually range anywhere between $40 and $80 per ton and will fill approximately 15 cubic feet. Seawalls also will vary in price. One of the major factors is how high the wall needs to extend above the water level. Some general prices range from approximately $120 to $250 per linear foot of shoreline.

The fourth primary response is to preserve the natural wetland that has been established west of St. Mary's Road just south of County Road 600 North. The Park Board may even choose to highlight this embayment as a wildlife area for the enjoyment of naturalists that visit the park. A structural sediment basin could then be constructed upstream from this area to retain incoming sediment, while the wetland could serve as a nutrient filter before the runoff enters the lake. Another area of similar circumstances is the west end of the Shurn Creek leg. Sediment basin or basins can be constructed upstream from this area to retain suspended sediment before it reaches this area to prevent additional sediment loading. A design study would need to be conducted to determine the exact specifications for both areas.

There are several costs involved with constructing sediment basins. Design costs will be approximately $300-$500 per basin designed. Construction of the basins will be approximately $1.50 per cubic yard of basin volume constructed. The cost of dredging would range from $2.00 to $5.00 per cubic yard. Disposal costs of the dredged soil would be variable due to hauling distance, storage time, and potential value as fill and/or topsoil material. A permit from the U.S. Corps of Engineers may be necessary based on how the dredged material is stored, where it is placed, and other factors.

The fifth primary response is to develop a written long term lake and watershed management plan which incorporates the above four listed responses. This is an important factor in organizing and enforcing these activities. The written management plan should have a foundation in Park policy as well as in county regulation and/or ordinance to provide for the long term care and protection of West Boggs Lake.

These five responses combine as the preferred alternative addressing nutrient loading, sedimentation, shoreline erosion, and sewage contamination at West Boggs Lake.

The livelihood and success of West Boggs Park is dependent upon the quality of West Boggs Lake. It is certainly in the best interest of the Park Board to invest the time and resources required to improve the overall water quality of the lake. The Park Board is in an influential position to elicit the assistance of public officials and private citizens to cooperate in accomplishing the goals and recommendations presented in this study. Through planning and diligence, the Joint Daviess-Martin Park and Recreation Board can protect the quality of West Boggs Lake for years to come before exceeding reparation potential.

Question: How many years before "reparation" time ~~has~~ will the needed recreation quality been been compromised enough to give West Boggs Park/Lake a negative reputation/visitation?

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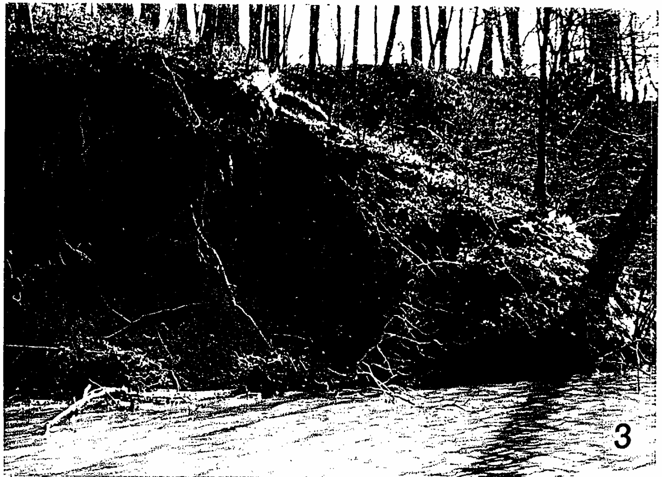
APPENDIX

1. Typical erosion of shoreline of unprotected undeveloped forest.

2. Excessive wave action continues to erode away forest shorelines.

3. Erosion of steep banks result in sloughing of entire trees with intact root mass.

4. Infrequently used dock areas threatened by shoreline erosion problems.



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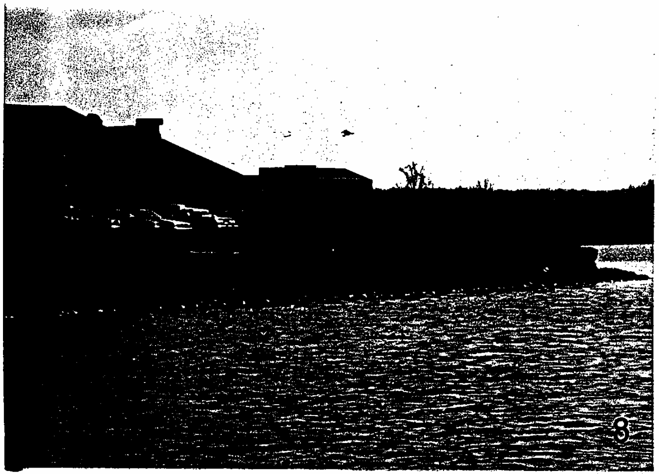
5. Numerous access areas are predetermined based on the severity of shoreline erosion.

6. Fallen trees due to shoreline erosion further complicate accessing the lake from private launches.

7. Proximity of commercial agricultural landuses. Note that the area between the shoreline brush and the stalk field is typically grazed.

8. The restaurant overlooking the lake has attempted to keep shoreline erosion in check with rip-rap.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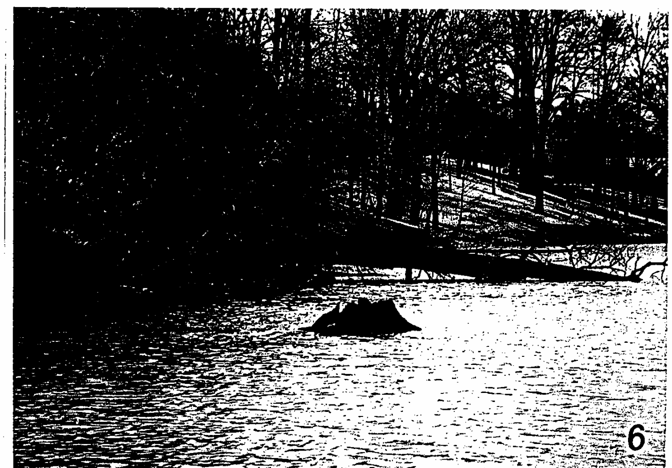
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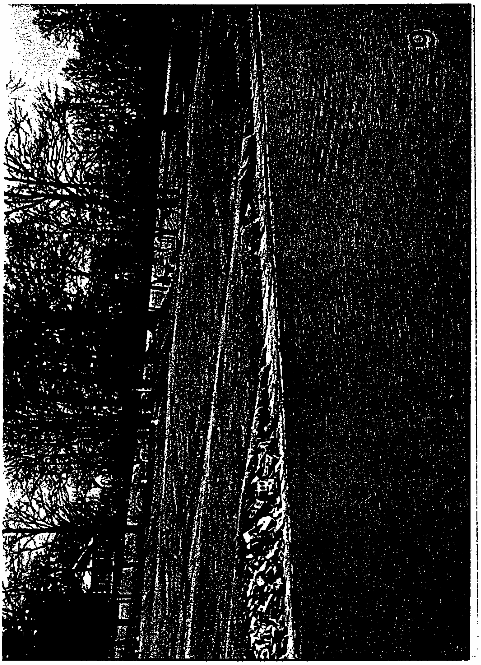
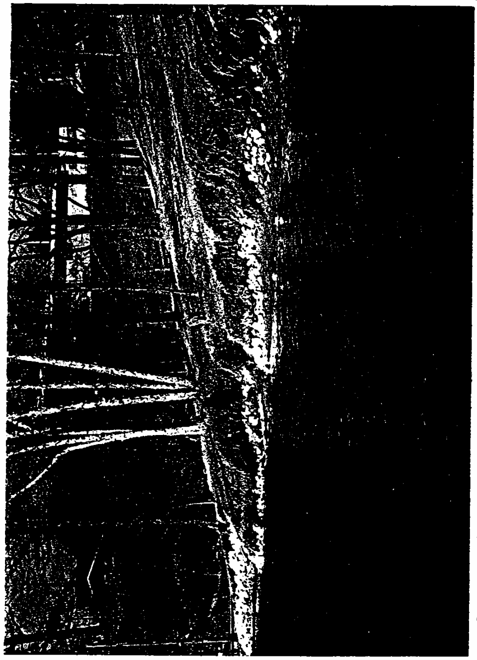
9. Some privately controlled areas of shoreline are subjected to creative measures of stabilization.

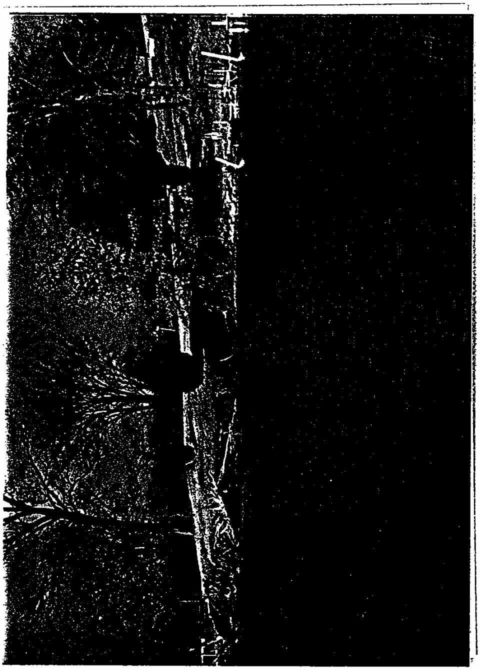
10. Rip-rap must be installed properly and in sufficient quantity to be effective.

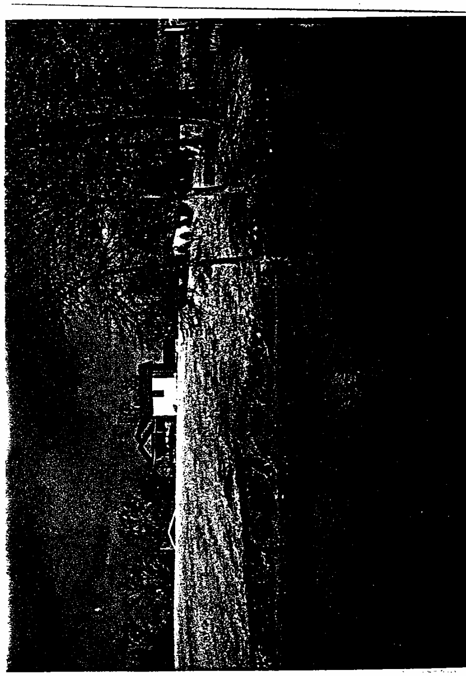
11. The privately owned real estate bordering the lake can experience significant losses in space and value due to shoreline erosion.

12. Previously developed access areas can be lost to unchecked shoreline erosion.







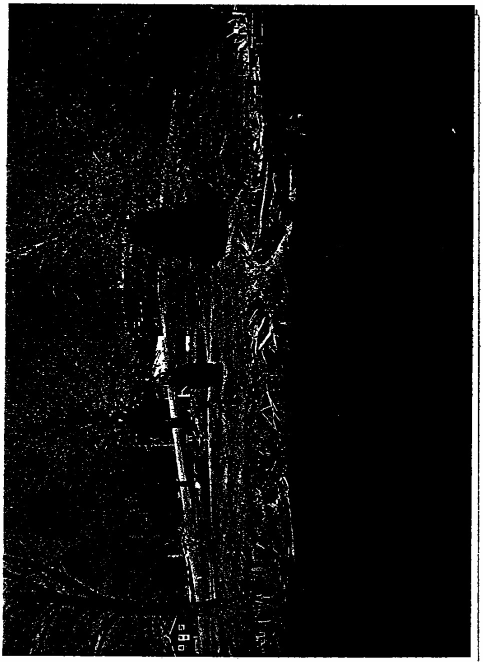


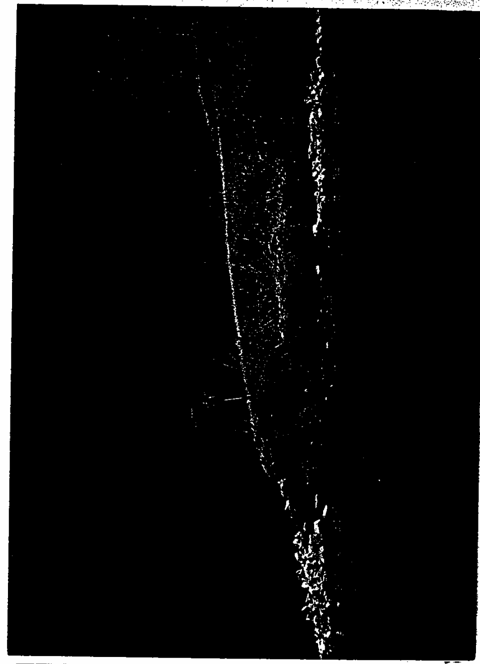
13. Unchecked shoreline erosion reduces the marketable value of all improvements made on lakeside properties.

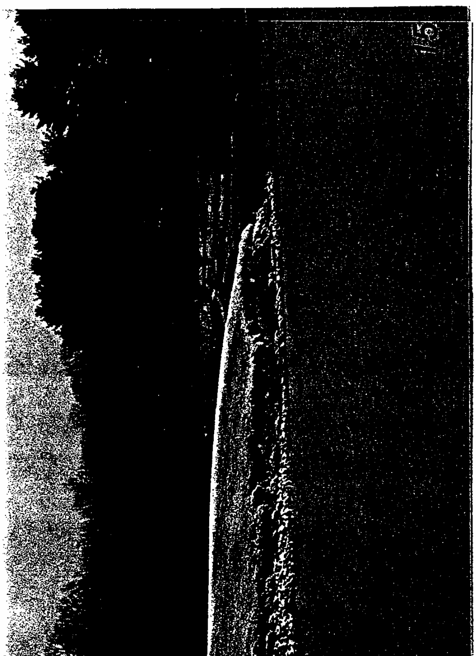
14. Continued erosion of park areas diminishes the aesthetic value of West Boggs Lake.

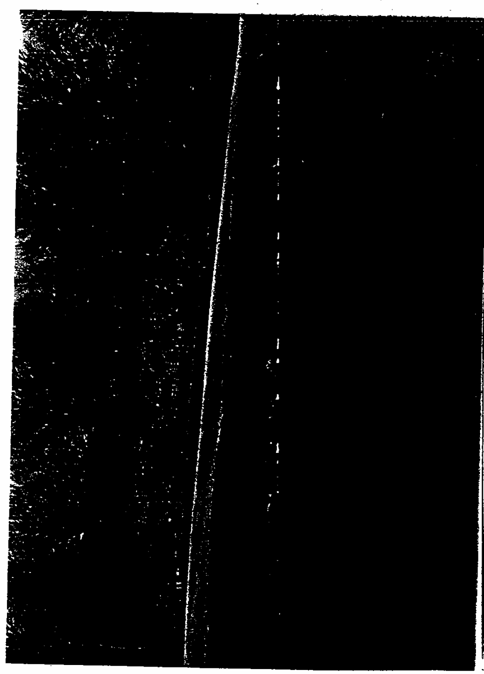
15. Public access camping and frolic areas need to be preserved.

16. Unprotected eroding shorelines diminish park interest and value.









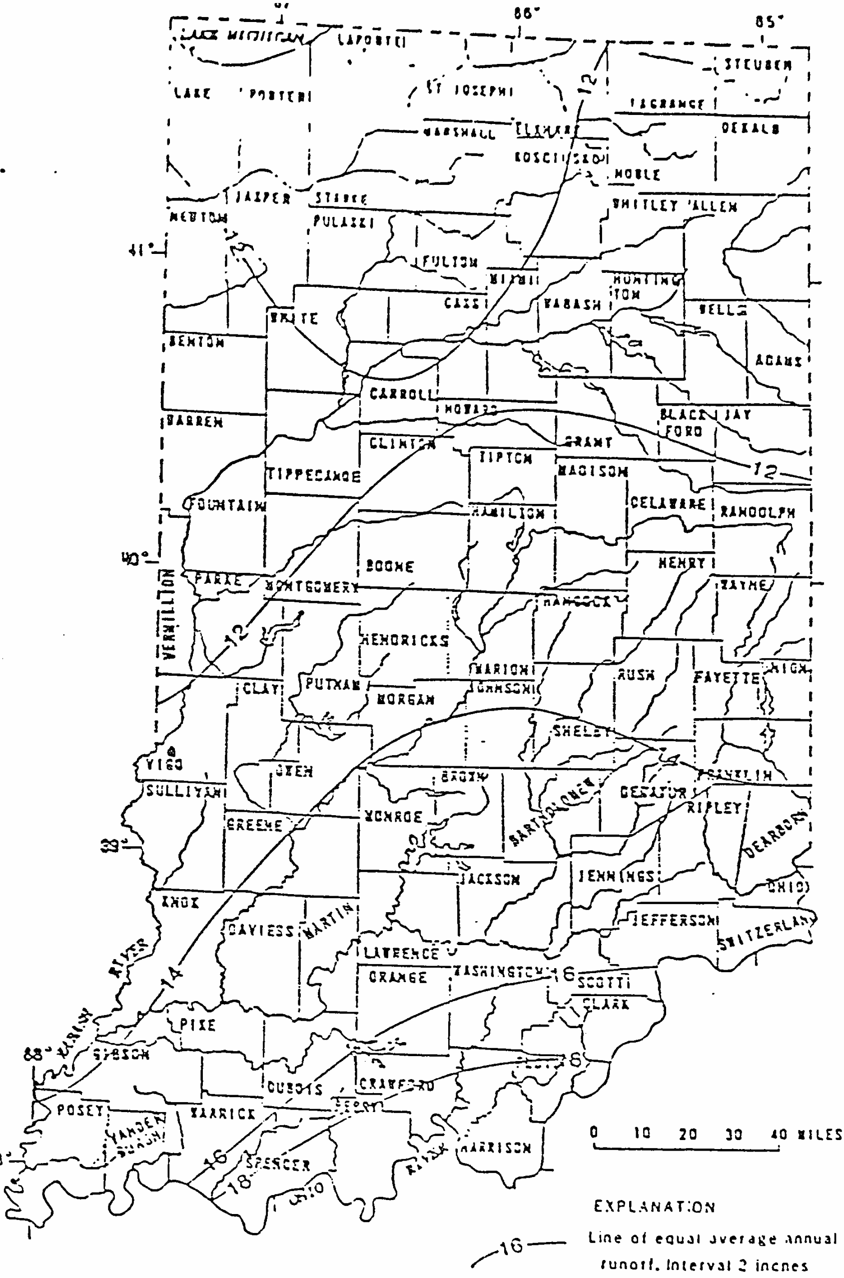
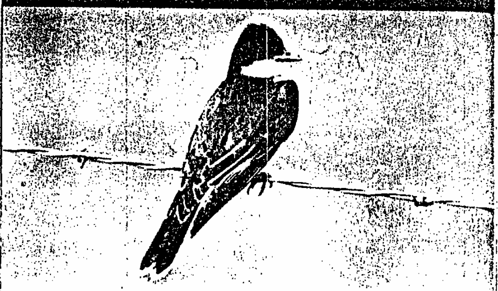


Figure 2.- Average annual runoff in Indiana, 1951-60.

(Data from Gebert, Graczy, and Krug, 1985)

421 Northern Shrike, 9–10½", p. 514

422 Loggerhead Shrike, 8–10", p. 514



423 Eastern Kingbird, 8½", p. 515

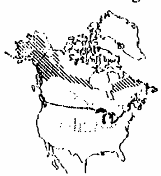
424 Pine Grosbeak ♀, 8–10", p. 698

425 Gray Jay, 10–13", p. 699

426 Gray Kingbird, 9", p. 484

421 **Northern Shrike**
(*Lanius excubitor*)
Shrikes (Laniidae)

Description: 9–10½" (23–26 cm). Robin-sized. Pale gray above, white below, with faint barring on underparts and a bold black mask *ending at bill.* Black tail with white edges. Stout, hooked bill. Usually seen perched in the top of a tree in the open.
Voice: Mixture of warbles and harsh tones with a Robin-like quality.
Habitat: Open woodlands and brushy swamps in summer; open grasslands with fence posts and scattered trees in winter.
Nesting: 4–6 pale gray eggs spotted with dark gray and brown. Nest a large mass of twigs, lichens, moss, and feathers, usually in a dense conifer.
Range: Alaska and the Labrador Peninsula to Quebec, Saskatchewan, and northern British Columbia. Winters south to Virginia, Texas, and northern California.



Unusual among songbirds, shrikes prey on small birds and rodents, catching them with the bill and sometimes impaling them on thorns or barbed wire for storage. Like other northern birds that depend on rodent populations, the Northern Shrike's movements are cyclical, becoming more adundant in the South when northern rodent populations are low. At times they hunt from an open perch, where they sit motionless until prey appears; at other times they hover in the air ready to pounce on anything that moves.

422 **Loggerhead Shrike**
(*Lanius ludovicianus*)
Shrikes (Laniidae)

Description: 8–10" (20–25 cm). Robin-sized. Slightly smaller than a Northern

Shrike, pale gray above, white below, with black face mask *extending over the bill;* dark crown.
Voice: Variety of harsh and musical notes and trills. A thrasher-like series of double phrases.
Habitat: Grasslands, orchards, and open areas, with scattered trees; open grassy woodlands; deserts in the West.
Nesting: 4–6 white eggs, spotted with gray and brown, in a bulky mass of twigs and grass lined with plant down and feathers, set in a thorny shrub or tree.
Range: Breeds from southern British Columbia, central Alberta, central Saskatchewan, southern Manitoba, southern Ontario, southern Quebec, and Maritime Provinces to southern Florida, the Gulf Coast, and Mexico. Winters north to Virginia and northern California.

In the southern half of North America this species is the counterpart of the Northern Shrike of boreal regions of Alaska and Canada. In behavior and choice of habitat the two species are essentially similar although the Loggerhead preys on insects more than its northern relative. Its flight is undulating with alternate rapid fluttering and gliding. Since it has no talons, it impales its prey—usually a small bird, mouse, or insect—on a thorn or barbed wire fence to facilitate tearing it apart then or at a later time; hence its other name, "Butcher Bird."

423 **Eastern Kingbird**
(*Tyrannus tyrannus*)
Tyrant Flycatchers (Tyrannidae)

Description: 8½" (21 cm). Dark gray above, blackish on head, white below; *black tail with white tip;* usually-concealed red crown patch.
Voice: Harsh and strident notes, often

SHORELINE PROTECTION

Leader:

STEVEN McCOMAS
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St. Paul, Minnesota

Panelists:

DAVID JANSEN
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Galena, Illinois

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INTRODUCTION

The objective of lake shoreline or streambank protection is to stabilize and protect these land forms against scour and erosion from forces such as wave action, ice action, seepage, and runoff from upland areas. Shoreline stabilization methods fall into two broad areas: nonstructural (vegetation or beach sloping) and structural (flexible structures like riprap, and rigid structures like seawalls).

EVALUATING THE PROBLEM

Characteristics found at the site determine the protection method. The source of the problem should be determined. Breaking waves or ice pushing onto shore are examples. Overland runoff or ground water seeping through the bank also cause bank failures. Several parameters to evaluate onsite include severity of existing erosion, shoreline use, soil type, slope, fetch of the lake, wave height, and wave runup. After these parameters are evaluated, a form of protection can be prepared.

DEFINITIONS

Fetch. The height of crashing waves on shore is an important design consideration. One factor affecting wave height is the fetch, the length of uninterrupted distance the wind blows over a lake. For detailed designs, the fetch is measured from a number of directions.

Slope. The slope is a measure of bank or shoreline steepness. For example, a basement stairway usually has a slope of about 1:1, meaning for a 1 foot length, there is a 1 foot drop. For a streambank or shoreline with a 4:1 slope, for every 4 feet of length the drop is 1 foot.

Wave Height. The height of waves crashing on shore is related to the fetch of the lake. Table 1 approximates the wave height attained in a 50 mph wind based on the fetch. For most inland lakes, a fetch of 2 miles is about the maximum, and most lakes do not experience wave heights greater than 3 feet above the still water level. Using Table 1, if a 50 mph wind blows across the lake uninterrupted for a distance of 1,500 feet, the expected wave height is 1.2 feet.

Wave Runup. When a crashing wave hits the shoreline, some runup occurs. The distance a wave will run up onto shore is a function of the wave height and the shore slope (roughness of the shore material is a factor not included in this approximation). Table 2 determines wave runup. For example, for a shoreline area with a slope of 4:1 and a crashing wave of 1.4 feet, the wave runup would be 1.5 times greater than the wave height, or 1.5 times 1.4 feet equaling 2.1 feet of runup.

NONSTRUCTURAL METHODS

Vegetation

Vegetation effectively controls runoff erosion on slopes or banks leading down to the water line; however, vegetation is ineffective against direct wave action or seepage-caused bank slumping. For erosion control, plants can be grouped into three categories: herbaceous plants (includes grasses and ground cover), shrubs, and trees.

The type of vegetation to establish depends on the angle of the slope. If the angle is steeper than 1:1, the soil is probably unstable and the possibility of establishing vegetative cover is slight. If possible, the bank face should be reshaped to a flatter slope. On slopes flatter than 3:1, a mowed lawn is feasible. On slopes between 1:1 and 3:1 a mowed lawn is difficult to maintain and other recommended options include unmowed grasses, shrubs, or trees.

Grass mixtures for slopes flatter than 3:1. Tall fescue and common Kentucky bluegrass mixture is appropriate for a mowed lawn and can be established in one year.

Grass mixtures for slopes flatter than 1:1. Red fescue and common Kentucky bluegrass mixture reaches a mature height of 12–18 inches and can be established in one year. Big bluestem, little bluestem, and switchgrass, reaching a mature height of 36–60 inches, are native prairie grasses and may take several years to become established.

Ground cover plants for slopes flatter than 1:1. These plants can be used instead of grass on slopes. They often are more attractive than unmowed grass and usually require less maintenance. They take one to several years to become established. Representatives include goutweed, bearberry, crown vetch, memorial rose,

Table 1.—Predicted wave height as a function of fetch for a 50 mph wind (from USDA SCS–Wisconsin Technical Guide, 1982).

FETCH DISTANCE (FT.)	WAVE HEIGHT (FT.)
500	0.7
1,000	1.0
1,500	1.2
2,000	1.4
3,000	1.7
4,000	1.9
5,000	2.1
7,500	2.6
10,000	3.0
12,500	3.3

Table 2.—Ratio of runup (R)/wave height(H) for various slopes (from USDA SCS–Wisconsin Technical Guide, 1982).

SHORE SLOPE HORIZONTAL:VERTICAL	RATIO
2:1	2.3
3:1	1.9
4:1	1.5
6:1	0.9
10:1	0.5

bugleweed, creeping juniper, and purple wintercreeper.

Shrubs for slopes flatter than 1:1. Shrubs are woody plants best transplanted in spring when they are dormant. Plant after the ground thaws and the air temperature is above 35° F. Planting can also be done in late autumn after the plants are dormant but before the ground freezes. They take one to two years to become established. Representatives include red chokeberry, gray dogwoods as well as other species of dogwoods, sumac, common juniper, common witch hazel, border privet, snowberry, and tatarian honeysuckle.

Trees for slopes flatter than 1:1. The process of establishing a woods on a bare slope is time consuming. Sow the area with grass seed and allow volunteer woody plants to grow as well. Use trees on slopes when a lake view is not necessary or a screen to block some other view is desired. Use shrubs where a view is wanted. Representative trees include red maple, silver maple, Junebush, paper birch, white ash, white pine, and black cherry.

When considering vegetation for slope stabilization, the property owner should seek professional advice but can do most of the work associated with planting.

For more information concerning vegetative applications ask for the brochure, Harmony With the Lake: Guide to Bluff Stabilization (Ill. Dep. Transportation, Chicago, Ill.). This brochure was used as a basis for most of the discussion in this section.

Erosion Control Mats. Erosion control mats serve as a reinforcing matrix for root systems. The mats, constructed of a nylon mesh or wood excelsior, are placed on top of soil to assist in seed germination, seedling protection, and erosion control. They control erosion on slopes carrying water with a velocity that makes it difficult for unaided vegetation to grow effectively. Different types of mats are recommended for different flow velocities (Table 3). Erosion control mats can be used in channels, in ditches, and on slopes, but are not designed to dissipate energy of direct wave action.

In summary, vegetation alone or combined with erosion control blankets controls erosion originating from the land side of the lake. The next series of protection methods will deal with bank and shore erosion originating from the lake side.

Beach Sloping

Beach sloping takes advantage of the ability of semifluid sands to dissipate the energy of the breaking and receding waves. A typical cross section is shown in Figure 1.

Design considerations:

1. Minimum thickness of the sand blanket is 1 foot.
2. Extend the blanket to a water depth two times the design wave height. If the design wave height is 1.0 foot, then the sand blanket should go into the water to a depth of at least 2 feet. If the final beach slope is 10:1, then the blanket goes into the lake 20 feet from shore (water depth

Table 3.—Ultimate velocities (lineal ft/sec) that various types of erosion control blankets can withstand under different soil conditions (from an American Excelsior Co. fact sheet).

	CLAY, CLAY LOAM, SILTY CLAY	LOAM, SILTY CLAY, SANDY CLAY LOAM	FINE SANDY LOAM, SILTY LOAM
Regular Curlex (Aspen excelsior, and plastic mesh) $0.51/yd²	4.8	4.8	3.9
High Velocity Curlex Blanket (heavy duty Curlex) $1.25/yd²	11.0	9.8	8.6
Enkamat 7010 (monofilament nylon mesh) $4.40/yd²	13.2	12.5	11.0
Enkamat 7020 (heavy duty monofilament nylon mesh) $6.70/yd²	17.5	16.5	14.5

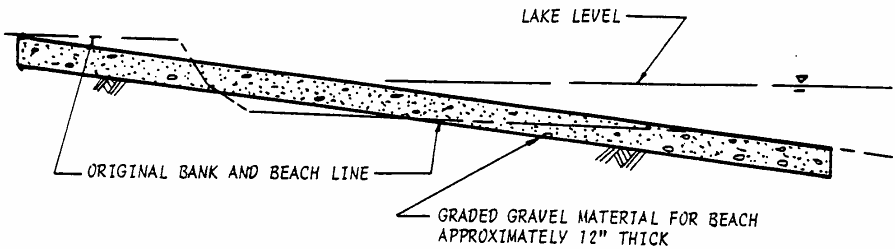

Figure 1.—Cross section of beach sloping. The final slope of the beach line is based on the size of material used.

will be 2 feet at 20 feet from shore at a slope of 10:1).

3. Extend the beach blanket the distance equal to the computed runup plus one foot.

4. The size of the material used and the final slope should be determined by a professional engineer.

One problem with beach sloping is that a strong longshore current may erode blanket material. Periodic replenishment will be necessary in this case.

STRUCTURAL METHODS

Riprap

Riprap is a flexible revetment (a revetment is a structure to prevent erosion of a bank) constructed of stone and gravel placed either on a natural slope or on an artificially graded shore to protect shorelines from wave action, ice action, and slumping because of seepage. A typical cross section is shown in Figure 2.

Design considerations include the following:

1. Riprap should be placed into the water 1.5 times the wave height below the still water surface.

2. Riprap should extend onto shore the runup distance plus 0.5 foot above the still water level.

3. The median rock size (diameter in inches) for various slopes and wave heights is shown in Table 4.

4. The minimum thickness of the riprap should be 2.5 times the median size.

5. A layer of bedding material to act as a filter should be at least 6 inches thick, or filter fabric should be used.

6. On slopes of 6:1 or steeper, the riprap at the lowest elevation (the toe) should be anchored.

Other Flexible Revetment Structures

Flexible structures move slightly under certain conditions, such as ice jamming, freeze–thaw cycles, and shifting of the bank. Riprap is one of a number of flexible revetment structures. Others include gabions (wire mesh baskets filled with rocks) and interlocking cement blocks that come in a variety of configurations. The Army Corps of Engineers (with stations all over the country) can provide more detailed information on these options, especially in the booklet, Low Cost Shore Protection . A Property Owner's Guide. Another source of information is the Soil

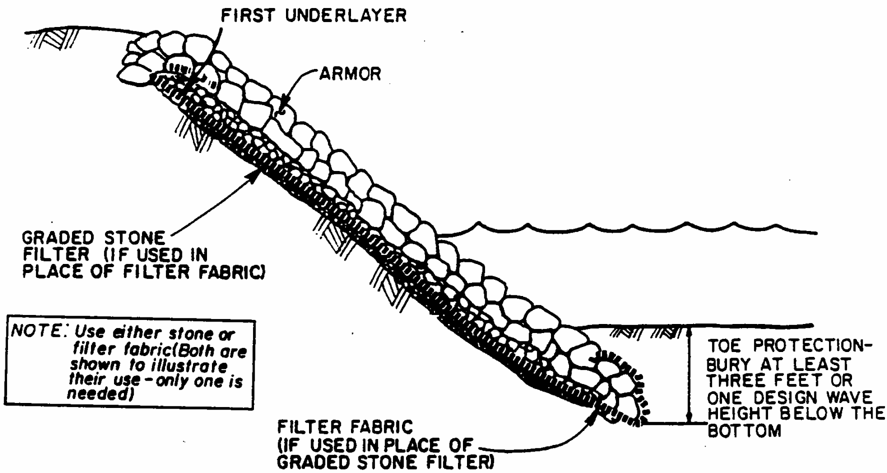

Figure 2.—Cross section of a riprapped shore.

Table 4.—Median rock size for various shore slopes and wave heights (from USDA SCS–Wisconsin Technical Guide, 1982).

SHORE SLOPE (HOR:VERT)	WAVE HEIGHT (FT)	MEDIAN ROCK SIZE (IN.)
2:1	1.0	4
	2.0	6
	3.0	8
3.1	1.0	4
	2.0	5
	3.0	7
4.1	1.0	4
	2.0	4
	3.0	7
6:1	1.0	4
	2.0	4
	3.0	6
10.1	1.0	4
	2.0	4
	3.0	4

Conservation Service in your county.

Seawalls, Bulkheads, and Retaining Walls

The names seawalls, bulkheads, and retaining walls are used interchangeably. These rigid structures are used where steep banks prohibit the sloping forms of protection. The seawall is placed vertically in soils and forms a barrier between the land surface and the waterbody. The land side is backfilled to absorb wave energy. The seawall primarily prevents land masses from sliding from the shore to the water and secondarily prevents wave action from damaging the shoreline.

Two types of seawalls are shown in Figure 3. A cantilever seawall is a sheet pile wall supported solely by ground penetration. An anchored seawall is similar to a cantilever structure but gains additional support from embedded anchors.

Design considerations include the following:

1. Steel sheet piles can be driven into hard soil and soft rock. Aluminum and timber sheet piles can be driven into softer soil.
2. For a cantilever seawall, the sheet piling should be driven deep enough to resist overturning, which usually requires penetration to a depth two to three times the free-standing height, depending on the foundation characteristics at the site.
3. For an anchored seawall, sheet piling should be embedded to a depth 1.5 to 2 times the free standing height. Again, the foundation characteristics may indicate shallower or deeper penetration.
4. The top of the seawall should be 1 foot plus runup above the stillwater elevation (use 1.5:1 curves for a smooth surface to determine runup).
5. Drain holes should be placed at regular intervals to facilitate movement of water from behind the structure. The drain holes should be backed with filter cloth or crushed stone filters.
6. Wing walls should be used to prevent flanking (erosion at the ends of the seawall). If the ends are not protected, erosion could produce a retreating shoreline at each end of the seawall.

QUESTIONS AND ANSWERS

Q. *Is it normal to grow vegetation on a sheer face?*

A. No, it is not normal. In the slide we saw, the owner wanted to keep the bank the way it was, so we used vegetation that would hold on a steep grade and made sure that it was not completely exposed to the rain.

Q. *When using rocks for shoreline protection, have you*

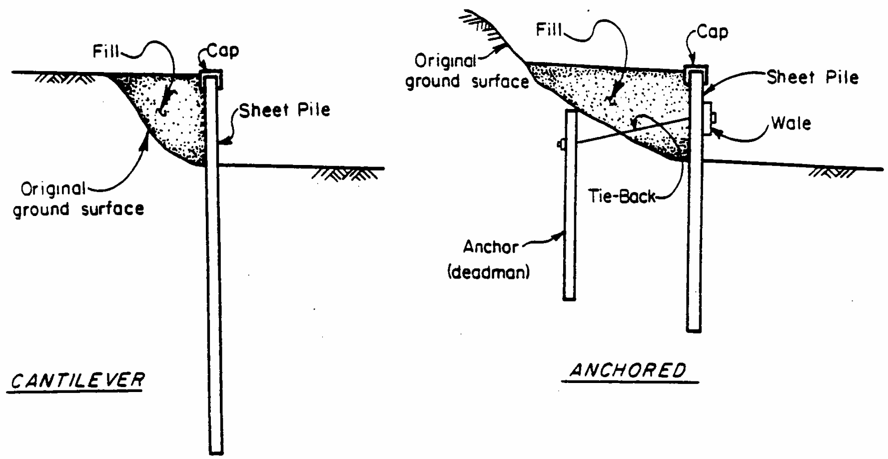

Figure 3.—Cross section of a cantilever and an anchored seawall. If timber is used for the sheet piling, a filter cloth backing should be placed behind the timbers on the land side.

developed a slope recommendation to eliminate ice pushing the rocks back up on shore?

A. Wave height is the primary design consideration. As far as ice action is concerned, the ice may loosen the rocks, but gravity will usually cause them to fall back down.

Q. *In Minnesota, we are finding that a 2:1 slope does not seem to prevent ice damage. Would a slope closer to 6:1 make a significant difference?*

A. Yes, it would make a difference. If you can get a 6:1 slope, use it.

Q. *Would drawing down the water level of a lake 2–3 feet, just before winter, help eliminate ice damage?*

A. Yes, a drawdown could be helpful, but you want to make sure that lowering the lake 2–3 feet does not put the water level at the toe of other property owners' seawalls. Wave action before freezeup could cause some problems. Also, you want to be sure that the water will return to the normal level in the spring.

Q. *Would a metal retaining wall tipped back at a slight angle conquer the ice problems?*

A. Yes, it would; a slope of about 15 degrees seems to prevent ice damage that would normally occur to a vertical retaining wall.